HUBBLE SPACE TELESCOPE FLAW

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

SECOND SESSION

JULY 13, 1990

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HUBBLE SPACE TELESCOPE FLAW

FRIDAY, JULY 13, 1990

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, DC.

The committee met, pursuant to notice, at 10:12 a.m., in room 2318, Rayburn House Office Building, Hon. Robert A. Roe (chairman of the committee) presiding.

The CHAIRMAN. Good morning, ladies and gentlemen, and the guests that are here this morning. The committee is gathered today to review a very serious matter that has received a great deal of public attention; namely, the recently discovered flaw in the Hubble Space Telescope optical system. Just two and a half months ago the successful launch of the Hubble filled us all, as we know, with excitement at the wealth of discoveries we would anticipate from this new window on space.

The problem with the Hubble is a bitter disappointment to all of us on the committee, as I'm sure it is to NASA, as I'm sure it is to the dedicated scientists and engineers who have worked on the program for many years. I think it's safe to say that compounding our frustration is, of course, the difficulty which seems to be emerging in reference to the shuttle fleet, which I trust that Admiral Truly will speak to, grounded due to hydrogen leaks and the Space Station Program reporting in some significant difficulties.

The committee has a long history of concern over the development of the Hubble telescope. We have held numerous hearings on the Hubble Program's management problems and cost overruns. Indeed, it was at one of those hearings that the Hubble Science Working Group's concern over the lack of instrument back-up was highlighted, and we were able to get a commitment from NASA, which they followed through on, to develop a back-up wide field/planetary camera. It now appears that the back-up camera may be the best hope for restoring some of the telescope's most important capabilities.

There is no question in our minds that this program is terribly important, and I know that other members have opening statements, so I'm going to cut my opening statement short. Again, I want to welcome all the witnesses that are here today, our colleagues, members of the committee, and the guests that we have in the room.

The chair now defers to the distinguished gentleman from Pennsylvania, our ranking member, Mr. Walker.

[The prepared opening statement of Mr. Roe follows:]

OPENING STATEMENT OF CHAIRMAN ROE

The committee is gathered today to review a very serious matter that has received a great deal of public attention: namely, the recently discovered flaw in the Hubble space telescope optical system. Just 2½ months ago, the successful launch of the Hubble filled us all with excitement at the wealth of discoveries we could anticipate from this new window on space.

The problem with Hubble is a bitter disappointment to all of us on the committee, as I'm sure it is to the teams of dedicated scientists and engineers who have worked on the program for years. Compounding our frustration, this difficulty is coming to light at the same time that the shuttle fleet is grounded due to hydrogen leaks and the space station program is reporting significant difficulties in coming to grips with its power, weight, and extravehicular activity requirements.

Our oversight responsibilities require not only that we determine the root causes of these problems, but also what, if any, is the significance of their convergence. Today we are only going to focus on one of the problems—the Hubble flaw. This committee is not under any illusions that we will have all of the answers at the end of this hearing. We do expect to come away with comprehensive understanding of the questions which NASA is planning to address and which ones the committee will have to grapple with in the days and weeks ahead.

This committee has a long history of concern over the development of the Hubble space telescope. We have held numerous hearings on the Hubble program's management problems and cost overruns. Indeed, it was at one of these hearings that the Hubble science working group's concerns over the lack of instrument backup was highlighted. We were able to get a commitment from NASA to develop a backup wide field/planetary camera. It now appears that that backup camera may be the best hope for restoring some of the telescope's most important capabilities.

NASA has an ambitious agenda for the rest of this decade, involving the development and operation of a number of large, very complex space systems. These include the remainder of the great observatories, the earth observing system, and of course the space station. We need to know if there are lessons to be learned from the Hubble experience that should be applied to these programs. This hearing is intended to help that learning process.

I want to welcome our very distinguished witnesses here today.

Mr. WALKER. Thank you, Mr. Chairman, and I thank you for holding the hearing today. I think it's an important hearing and one that this committee needs to follow up in detail after we finish here today.

It is certainly unfortunate that this morning's session is necessary. When the Hubble telescope was launched two months ago, all of us were excited about the possibilities which this unique instrument presented for the observation of our universe. As we now know, it appears that there is a flaw in the telescope's lens. Apparently, Hughes-Danbury has pledged its cooperation in the investigation of how the mirror's flaw was able to escape detection, but we need to look into what happened within NASA, what happened outside NASA, and today's hearing begins that process.

We are here today as a committee to gain an understanding of the nature of the problem and how it occurred and its implications for science users. It must also be said that part of the problem lies within Congress itself. For years, Congress, in the fatality of its policies, has been nickel and diming NASA, and I think that has had a consequence. The decision not to fully test the mirrors was made in large part for budgetary reasons.

I think it's high time that Congress realized that large, costly projects cannot be run on a shoestring, and they can't just be run from appropriation to appropriation. We have to have what this authorizing committee has suggested now for some time. We have to have long term authorizations for these programs so that we can move ahead with them in some sort of continuity. The problem is

that we haven't been able to convince the people on the other side of the Capitol of that, and we continue then to either not have authorizations at all, or we continue to go from appropriation, and these kinds of problems continue to accrue.

I'm certainly not in any way condoning whatever cost overruns might have taken place or any failures in oversight either by NASA or by the Congress, but I do want to point out that as we go about the process of assigning blame, we need to make certain that we not neglect a self-examination of how the budgets are made up and how authorizing and appropriating affects the outcome of long term projects.

Thank you, Mr. Chairman.

[The prepared opening statement of Mr. Walker follows:]

OPENING STATEMENT OF MR. WALKER

Mr. Chairman, thank you for holding this hearing today. It is certainly unfortunate that this morning's session is necessary. When the Hubble telescope was launched 2 months ago, all of us were excited about the possibilities which this unique instrument presented for the observation of our universe.

As we all know, it now appears that the flaw in the telescope's lens occurred as a result of improper grinding. Apparently Hughes Danbury has pledged its cooperation in the investigation of how the mirror's flaw was able to escape detection.

We are here today as a committee to gain an understanding of the nature of the problem and how it occurred, and its implications for science users.

It must be said that part of the problem lies with the Congress itself. For years we have been nickel and diming NASA for years. A decision not to fully test the mirrors was made in large part for budgetary reasons. I think that it is high time that we in the Congress realize that large, costly projects cannot be run on a shoestring from appropriation to appropriation (and without an authorization) and escape serious negative consequences. I am not condoning the cost overruns or the apparent lack of oversight—I only want to point out that in assigning the blame for the Hubble fiasco, we should not neglect a thorough self-examination of the Congress' role.

I look forward to hearing the witnesses' testimony.

The CHAIRMAN. I thank the distinguished gentleman from Pennsylvania.

The chair recognizes the distinguished gentleman from California.

Mr. BROWN. Mr. Chairman, I have a very brief statement which, in large part, reiterates some of the very crucial points that Mr. Walker made, and I ask unanimous consent to insert it in the record.

The CHAIRMAN. No objection, so ordered.

[The prepared opening statement of Mr. Brown follows:]

STATEMENT OF OF CONGRESSMAN GEORGE E. BROWN, JR.

Hubble may be yet another example of what happens when we run highly complex research and development programs on tight-fisted budgets. As with the space shuttle *Challenger* accident, we may have been penny wise and pound foolish. Though some may want to point the finger at NASA failing to require an end-to-end test of the Hubble space telescope optical system, NASA may have been constrained by budgetary pressures to keep the cost of the program down. If we are going to build future Hubble telescopes, keep a space station flying for decades, launch large spacecraft to observe the Earth, and ultimately send humans to other parts of the solar system, we have to find a way to provide the funding that is necessary to keep these programs running smoothly and safely. This is a two-way street. NASA and the administration must provide accurate cost estimates that include adequate margins of safety to protect against the inevitable difficulties and cost overruns encountered by advanced development programs. The Congress must be willing to make a long-term commitment to adequately fund these programs once they are started. In-

stead of causing us to point fingers, Hubble's troubles should prompt a constructive and necessary debate on how the exciting space exploration projects we now envision can be carried out without repeating the mistakes of the past.

The CHAIRMAN. The chair recognizes the distinguished gentleman from Wisconsin.

Mr. SENSENBRENNER. Mr. Chairman, a few weeks ago, we received the very disappointing news that the optical system on the Hubble Space Telescope is flawed. This is a defect of enormous proportions. This problem will drastically reduce and degrade the amount and quality of science which can be performed with this $1.6 billion telescope, at least for the next few years.

The history of this program has been one of management problems, technical problems, schedule delays, and substantial cost overruns. Nevertheless, this committee continued to support the Hubble Program because of our great expectations, expectations based on promises of tremendous discoveries about the origin and composition of the universe.

NASA has expressed its confidence that the optics problem can be overcome, and eventually the Hubble will be restored to its original capabilities. I remain hopeful as well as commend the agency for responding so quickly to the problem by establishing an independent panel to ascertain exactly what is wrong with the optics, what caused the flaw, and how the defect could have escaped earlier detection. At the same time, I must admit my overall reaction to this latest revelation is one of frustration and growing concern.

NASA has had many successes to its credit over the years; however, I am afraid that the discovery of this latest problem, timed so perfectly with the unfavorable news being reported on the Shuttle and Space Station Programs, provides increasing evidence that NASA may be embarking on programs which are too technologically complex to effectively manage and to deliver on budget.

The experiences with Hubble suggest that there are serious deficiencies in NASA's ability to estimate costs and to monitor contracts and an organizational attitude which places too low a priority on risk management, testing and verification. Perhaps these are all symptoms of NASA's unwavering confidence and optimism to meet every challenge despite limited resources.

Let me say that this statement is not an adverse reflection on the management of Admiral Truly over NASA. Admiral Truly came on board long after the space telescope was completed and put in the warehouse waiting for the shuttle to come back on line and to launch it, and the mistakes that we are discussing here today are those that were made in the early part of the last decade. Nevertheless, I think that it is important that NASA, the Congress, and the Administration learn from this terrible mistake so that it is not repeated and so that we do have better risk analysis and management capabilities than we have had in the past.

I believe that the real value of today's hearing and of our continued investigation into this matter will be a better understanding of the institutional weaknesses both of NASA, the Congress, the budgetary process, and the OMB, and with that, a better perspective for evaluating future policies.

[The prepared opening statement of Mr. Sensenbrenner follows:]

OPENING STATEMENT OF F. JAMES SENSENBRENNER, JR.

Mr. CHAIRMAN: A few weeks ago we received very disappointing news that the optical system on the Hubble space telescope is flawed. A defect of enormous proportions. This problem will drastically reduce and degrade the amount and quality of science which can be performed with this $1.5 billion telescope, at least for the next few years.

The history of this program has been one of management problems, technical problems, schedule delays and substantial cost overruns. Nevertheless, this panel continued to support the Hubble Program because of our great expectations—expectations based on promises of tremendous discoveries about the origin and composition of the universe.

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At the same time, I must admit that my overall reaction to this latest revelation is one of frustration and growing concern. NASA has had many successes to its credit over the years. However, I am afraid that the discovery of this latest problem, timed so perfectly with unfavorable news being reported on the shuttle and space station programs, provides increasing evidence that NASA may be embarking on programs which are too technologically complex to effectively manage and deliver on budget (is not capable of effectively managing, and delivering close to "on-budget", large, technologically complex programs). The experiences with Hubble suggest there are serious deficiencies in NASA's ability to estimate costs and monitor contracts, and an organizational attitude which places too low a priority on risk management, testing and verification. Perhaps these are all symptoms of NASA's unwavering confidence and optimism to meet every challenge despite limited resources.

Mr. Chairman, I believe the real value of today's hearing, and of our continued investigation into this matter, will be a better understanding of the institutional weaknesses of NASA, and with that a better perspective for evaluating future projects.

The CHAIRMAN. I thank the distinguished gentleman from Wisconsin.

The chair has a housekeeping matter. I'd ask unanimous consent without objection that permission is granted for coverage of this meeting by television, radio, and still photography. No objection, so ordered.

If I could ask our colleagues, I know there are people who have some other opening statements they would like to make, but if we spend all morning making opening statements, we're not going to get the value of the people that have come here to testify and bring elucidation, if you like, to the committee. So without objection, if anybody has any opening statements they would like to make at this time, please place them in the record, and then we will proceed to go to our witnesses.

We are setting up this morning with three panels, and the first panel consists of Admiral Richard H. Truly, of course, the distinguished Administrator of the National Aeronautics and Space Administration. He is accompanied by Dr. Lennard A. Fisk, who is the Associate Administrator at the Office of Space Science and Applications, also with NASA.

The chair will recognize the distinguished Admiral Truly, the Administrator of NASA.

Admiral Truly.

STATEMENT OF ADM. RICHARD H. TRULY, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, DC

Admiral TRULY. Thank you, Mr. Chairman. I appreciate the opportunity for Dr. Fisk and I to come and testify to this committee and lay on the table the facts of the matter as we understand it today on the Hubble Space Telescope, and I would also like to update you very briefly on the status of the Space Shuttle.

This is not the type of hearing that NASA likes to come to, because it deals with problems. We pride ourselves in mission success and in safety. The aberration in the Hubble Space Telescope to properly focus is unacceptable to the NASA team, and we take full accountability for this anomaly. I'd like to say what the problem is. It's called a spherical aberration, and in simple terms, what appears to be the situation with the mirror is that it is very perfectly smooth and better than its specification, which was to be smooth within about 1/50th of one wavelength of light at a particular frequency. However, there is an error in the curvature of the mirror that is very symmetrical across the mirror.

It is too early to say specifically what the exact cause of this error was. In hindsight, it appears that a likely candidate is that it was a simple error made in the manufacture of the primary mirror, and if that proves to be the case, I'm sure that we will determine that the error was avoidable. I would like to point out that the error was actually made over 10 years ago, during the manufacture, we think, of the mirror.

We have appointed an investigation review board, headed up by Dr. Lew Allen, who you will hear from later on this morning. This board was established and chartered very simply to determine three things: one, when did the problem occur?; two, how did the problem occur?; and three, why did we not discover it before launch? You will hear from him later on today.

Meanwhile, on another tack, NASA is determining the scientific capability of the existing spacecraft and determining the best possible fix, and it is fixable, to regain the full operating potential of the Hubble Space Telescope. I can assure you that NASA will do everything possible to correct this deficiency as quickly as possible and as capably as possible.

Based on the lessons that have already been learned in the past from the Hubble Space Telescope management problems during this period when this error was made, NASA has already made a lot of changes in its Space Science Programs since Hubble was initiated to assure that a problem of this magnitude would not occur again. But space is risky business, and pushing the edge of technology does present technical risk.

However, in this instance, the high technology components of the program frankly seem to be working well. The complex part of the telescope is operating very close to perfectly. The problem seems to be isolated in the mirror itself.

I'd also like to take this opportunity very briefly to give the committee an update on the investigation of the hydrogen leaks in the two Space Shuttle orbiters. First of all, let me say that this issue is a very different matter entirely and one that this committee

should be very interested in. This is a case where our risk assessment system and our risk management system worked as advertised. We detected what could be an extremely hazardous situation with a hydrogen leak, and we have not been embarrassed to stop the flights until we correct it.

The situation this morning is that we have the hardware from Columbia in test at Downey, California, and we have narrowed the various possible leak paths to a highly suspect shaft seal, and we believe to be narrowing in on that cause very quickly. Of the other vehicle, this morning while this hearing is being conducted, we are conducting a tanking test on the Atlantis on the launch pad, and that test is underway, and I am confident that the Downey tests and this test will let us understand that and that we'll be back to flight, I hope, very quickly. Again, the system works.

Based on what I've read in the last few weeks, it's clear that this incident with Hubble, coupled with the grounding of the shuttle fleet to fix the hydrogen leak, has eroded confidence in NASA and the ability of NASA to implement challenging programs and might tempt some to shy away from the future presented to Congress here in the budget that you are also deliberating. Frankly, I think nothing could be further from the truth, and this mishap should not be a condemnation of important science, technological prowess, or large undertakings.

In complex programs that involve human beings, failures do occur, and anomalies do happen. That does not make them acceptable or tolerable. At NASA, we minimize the risk of failure, but we cannot totally eliminate it. Still, any failure is one failure too many. Especially in the case of an instrument such as the Hubble Space Telescope that received special care and attention and was the hallmark of a new, exciting era of space exploration.

Fortunately, in the case of Hubble, there is a solution to the problem, but that does not lessen the severity of the problem or the challenge to the NASA industry team. I know I speak for the entire NASA team when I tell the committee that this error is unjustifiable but that it does exist and that we must now take the necessary steps to make sure that such an occurrence not be repeated.

Mr. Chairman, if I might ask to see if Dr. Fisk would like to add anything to remarks, but I thank you again for the opportunity for us to help you put the facts on the record.

The CHAIRMAN. I thank you, Admiral Truly.

Dr. Fisk.

STATEMENT OF DR. LENNARD A. FISK, ASSOCIATE ADMINISTRATOR, OFFICE OF SPACE SCIENCE AND APPLICATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, DC

Dr. FISK. Thank you very much. Allow me just to elaborate on a couple of points that Admiral Truly made. As he pointed out, the spherical aberration in the mirrors is a very simple one.

The CHAIRMAN. Why don't you, for the record, if I may interrupt you there, explain what you mean by a spherical aberration.

Dr. FISK. A spherical aberration is where all points on the surface of the mirror do not focus light at precisely the same point. If you had a perfect optical system, all points on the surface of the mirror would focus light at the same focal point. In the case of Hubble, we are off by a bit.

Now, I want to emphasize the kind of distances that we're off. The surface of the mirror appears to be in error by approximately 1/5000th of an inch—1/5000th of an inch. Now, that's not something you're going to look at and see, but by optical standards, that's off by quite a bit, and that error is unacceptably large in an optical system. But the surface of the mirror appears to be in error by about 1/5000th of an inch, and that causes the light from all points of the mirror to focus over a very narrow spread in distances, measured in millionths of an inch, but nonetheless spread so that there is no single point where you can put your cameras and focus all the light.

The advantage, however, is that the aberration is spherically symmetric, and by that I mean that if you looked at the edge of the mirror, if you went all around the edge, all the points at a single radius from the center——

The CHAIRMAN. How large is the mirror?

Dr. FISK. The mirror is 94 inches. So suppose you went out to the point that you were near the edge of the mirror and you went around in a circle around the center. All the light from that circle would focus at precisely the same point. But if you took a smaller radius, if you took an internal circle here, that would focus at a slightly different point. So the aberration is spherically symmetric around, but as you go in radius outward from the center of the mirror, not all points focus at the same point.

But because it is so simple in the sense that—you could have had a worse pattern, in which, say, the right-hand side of the mirror focused light at one point and the left-hand side focused it at some other point. That would be a far more complicated pattern and therefore much harder to correct, but because the aberration is symmetric around the mirror, it is a very simple correction to make.

And as the chairman pointed out in his opening remarks, we have the second generation of instruments underway for Hubble, the WFPC-II, the Wide Field/Planetary Camera II, which does the bulk of the observations in visible light, and that is scheduled to be ready—on the current schedule, before this flaw was found—ready to be inserted in the telescope in June of 1993, and it is a simple matter to change one mirror. I would say it is a very simple correction to make.

Now, the second consequence of the simplicity of the error is, as Admiral Truly pointed out, it is probably a manufacturing error. If you had had an error that was introduced by gravitational sag or the lack of it on orbit, if you had had some thermal change in the mirror, you would have expected to get a far more complicated pattern. But because the mirror is perfectly raw, you expect it to have been introduced in the manufacturing process, and that's what Dr. Lew Allen's panel is designed to find out.

The one point I would like to make that we don't lose sight of, the telescope is going to be very busy in the next few years before we

make any permanent corrections to it. The telescope is an excellent instrument in the ultraviolet, and let me try to give you a measure of that. There's only one satellite that does observations in the ultraviolet. That's the International Ultraviolet Explorer, which was launched in 1978, one of the most productive astronomy satellites that NASA ever floated.

Hubble has a factor of 100—Hubble, as it is today with the aberration in it, has a factor 100 times more sensitivity than the International Ultraviolet Explorer has, it has 100 times better spectral resolution, and it is able to do imagery in the ultraviolet, which is something we have never done with a satellite before, and those observations can be made today without correcting the aberration.

We can also do spectroscopy with the Hubble Space Telescope, we can do photometry with the Hubble Space Telescope. We are degraded in visible light because of the aberration. We are comparable today to a good ground based--in fact, an excellent ground based—telescope, but we're not better than an excellent ground based telescope in visible light with the aberration. But that's what can be fixed with the second generation of instruments.

But we're also exploring today image reconstruction, looking at the images that the telescope produces today and applying very sophisticated image reconstruction techniques to get the maximum information out of that and improve the resolution. And we are optimistic that for relatively bright sources and high contrast sources that that will be a very effective technique to make the telescope work today in visible light.

Bottom line, the telescope will be very busy over the next few years, the telescope will be fixed with the second generation of instruments, and when we look over the 15-year history of this program, it's designed to work for 15 years, we will get from the Hubble Space Telescope everything that we expected to get from it when we launched it.

[The prepared statement of Dr. Fisk follows:]

HOLD FOR RELEASE
UNTIL PRESENTED BY
WITNESS
JULY 13, 1990

Statement of

Dr. Lennard A. Fisk
Associate Administrator for
Space Science and Applications

National Aeronautics and Space Administration

before the

Committee on Science, Space and Technology
House of Representatives

July 13, 1990

Mr. Chairman and Members of the Committee:

I am pleased to have this opportunity to report to the Committee on the status of the Hubble Space Telescope (HST).

I am here today to report on NASA's preliminary assessment of tests conducted on HST over the weekend of June 23-24. These tests suggest that HST is experiencing what we believe is spherical aberration, or an inability to focus light into a single, precise point. I want to stress that our understanding of this anomaly is incomplete and it remains under study; however, NASA feels it is important to maintain our policy of openness with the public and the Congress. In this regard, I am prepared to provide whatever briefings and testimony you deem appropriate to keep you and the other members of Congress fully informed of this situation as it unfolds.

First, this spherical aberration is significant because it prevents Hubble from fulfilling one of its primary requirements, namely, that "70 percent of the total energy of a stellar image must be contained within a radius of 0.10 seconds of arc." Hubble is

currently able to focus only 15 percent of an image's energy into that same area.

However, and let me stress this again, this aberration will not prevent Hubble from answering the fundamental questions about the universe it was built to investigate. New, exciting, and unique science will be conducted using Hubble in the near-term and over its entire 15-year lifespan, beginning almost immediately. Hubble will not be able to conduct certain scientific activities in the near-term, but it will be able to substitute significant science in a number of equally important areas. Over the next few years, Hubble's capabilities will be restored, allowing us to recapture the science that will be deferred in the interim.

It is important to remember that NASA was established to do challenging missions; missions that require men and machines that push the envelope of technology to its limits. The true test of the Hubble team (NASA Headquarters, NASA Field Centers, HST's contractors, the Space Telescope Science Institute and the scientific community at large) should be, and must be, how we react when confronted with adversity; how quickly and efficiently we overcome this problem. I am confident that we can, and will, overcome this.

Clearly, the first step has to be finding out the cause of this aberration. To accomplish this goal, I have established the Hubble Space Telescope Investigation Board to investigate the cause of this anomaly. This Board will be a working group charged to review, analyze, and evaluate the facts and circumstances regarding the manufacture, development and testing of Hubble's Optical Telescope Assembly.

This Board is chaired by Dr. Lew Allen, the Director of the Jet Propulsion Laboratory, and is composed of world-renowned experts in optical systems and spacecraft quality control. The other members of the Board are:

Charles P. Spoelhof
(Retired) Vice President, Eastman Kodak Co.

George A. Rodney
NASA's Associate Administrator for Safety and Mission Quality

John D. Mangus
Head, Optics Branch, Space Technology Division
NASA's Goddard Space Flight Center

Prof. R. (Bob) Shannon
Director, Optical Sciences Center
University of Arizona, Tucson

Dr. Roger Angel
Professor of Astronomy, Steward Observatory
University of Arizona, Tucson

The Board held its first meeting in Washington, D.C. on July 5 and 6. A copy of the Board's public statement following its first session is enclosed.

The second step is to continue the process of characterizing this problem and to understand its impacts on the scientific goals of Hubble. Our goal will be to maximize the scientific return of Hubble in the near-term, as well as over its 15-year lifespan. Two weeks ago, the Hubble Science Working Group authored a white paper which summarizes their preliminary assessment of the impact on the science program. With your permission, I request that the Science Working Group's white paper be entered into the record.

In the next few months, NASA will be working with the Space Telescope Science Institute (STScI) and the Science Working Group to replan the scientific program for Hubble. As Dr. Peter Stockman, Deputy Director of STScI, stated before the Senate Subcommittee on Science, Technology and Space on June 29, 1990, our initial assessment is that approximately 50 percent of the observations originally scheduled for HST are still viable. Again, as Dr. Stockman reported previously, part of the peer review panel that selected HST's first-year observations will be reconvened to reevaluate the proposals in light of Hubble's current strengths. It is important to remember that since there were ten times as many observations approved originally as could be scheduled during the first year, there is little doubt that HST will continue to be oversubscribed.

The third step of this process will be to develop and implement a long-term solution to the aberration. Our preliminary assessment is that the inclusion of a relatively small corrective mirror or lens in the front of the second generation instruments should eliminate the scientific impact of this aberration. We believe that this solution should be very straightforward and should not result in a significant cost or schedule impact in the development of the new instruments. NASA will also explore accelerating the delivery of the new instruments, especially the second Wide Field/Planetary Camera, to further minimize the scientific impact.

Remember, what we are talking about here is not 'losing science' as has been reported in the press; but rather, altering the mix across areas of science for the next few years. During this interim period, we will be deferring some significant science, primarily in visible light imaging, while substituting equally significant science, i.e. ultraviolet observations, spectroscopy and astrometry. The bottom line is that visible light imaging will occupy a smaller portion of on-target observation time while ultraviolet observations, spectroscopy and astrometry will occupy a larger portion during the first few years. We fully expect that after the second generation instruments have been delivered on orbit, that all the science that is deferred will be successfully completed. And when examined over its full 15-year operational lifetime, the relative distribution of observation time across the science program will be more evenly distributed.

I should also note that there appears to be the potential for acquiring additional visible and ultraviolet imaging science. We have formed a "tiger team" to review

the potential benefits of various image processing or reconstruction techniques. It is thought that such techniques could provide up to three times more resolution than the current performance and thereby make some of the imaging science viable. We should have some more definitive answers on this by mid-August.

In conclusion, I would like to emphasize three points. First, we are committed to determine how and when the problems in the Optical Telescope Assembly occurred which lead to the observed spherical aberration, and how this aberration could go undetected prior to launch. Second, we are committed to strive forward in understanding this problem relative to its impact on the scientific goals of the program and subsequently maximize the scientific return of this facility both in the short term and the long term. Finally, we are committed to develop and implement a long-term solution to the aberration to assure that the full potential of the Hubble Space Telescope is realized. I believe that we will witness discoveries by the scientific community that will be characterized as world class. As Dr. John Bahcall so aptly stated recently "When we read the history books of this decade, we will not notice the prescription for the Hubble mirror was slightly askew. But we will notice that we opened major new chapters in the understanding of the universe. It will be an intellectual revolution."

Thank you very much.

The CHAIRMAN. I thank you, Dr. Fisk.

Before I call on other members, I think that some clarification has to be made, if I may. Number one, we use the word "simplicity," and I think you're using in the technical term, not simplicity in the order of the magnitude of the problem we're faced with. I mean, it's not a simple problem by any stretch of the imagination to correct something that's been manufactured incorrectly, assuming that that's what the panel ultimately determines.

So I don't think it's really that simple, but I think it's important to point out and get on the record, as I understand it, the original—oh, what would you say?—the original program for the Hubble was to be based on a 15-year period of time. Is that correct?

Dr. FISK. That is correct. That is the timeframe.

The CHAIRMAN. My understanding was that over that 15-year period of time, we would be doing our research work in our use of the Hubble and all different kinds of testing and instrumentation and so forth, and we had people that applied to participate in the use of that time. As I understand it, the panel that was established to determine in priority the uses would be placed to, that was determined, and there was not enough time, of course, to accommodate everybody that wished to do everything they wanted to do. That's a statement of fact, is it not?

Dr. FISK. That is correct.

The CHAIRMAN. So therefore NASA selected, or the panel that NASA established, selected the order that people would be using the machine. Isn't that correct?

Dr. FISK. We received 10 times the number of requests for time on the Hubble as we were able to accommodate.

The CHAIRMAN. Right. Now, where I'm coming from, it seems to me that the first and foremost issue in the minds of myself and, I think, most of the members and the people of the country, is this thing a dud? I have to bring it down to that simplicity. Is it a dud?

Dr. FISK. It isn't——

The CHAIRMAN. Let me finish. The question is not complete. I want to just let that sink in. Is it a dud? That's number one. Did we spend a billion and a half or more dollars and build a telescope that, according to some of the press, doesn't produce what it was supposed to produce? And can never produce what it was supposed to produce, some of the articles I have read. Should we have spent this kind of money and all of the problems and frustrations of this Hubble over the period of time, or did we waste the money?

Therefore, I think that people would ask the basic question, what is the true story on the Hubble and its use? What is the optimum yield? Over the period of time, will the Hubble yield the technology and the work that we're talking about doing, originally, and meet those goals originally laid out for it? That's the question.

The second question I follow on with, and they're not that complicated, the second question one comes back and says, when we talk about changing instrumentation, I don't think you clarified that enough. You're talking about changing lenses and instrumentation that will in effect take advantage of the aberration that's taking place so that you'll be able to get the yield out of the second phase instrumentation that you're going to fly up there in 1993. I think that's very important.

We're not going to be able to change the mirrors, because we're not going to bring it back, but we're going to achieve the goal of getting the yield out of the Hubble by changing the lenses and so forth and adapting the second phase instrumentation to achieve that goal. Is that a correct interpretation?

Dr. FISK. Can I answer now?

The CHAIRMAN. Now you can answer.

Dr. FISK. In answer to your first question, categorically, Hubble is not a dud. Hubble is going to be capable over its 15-year history of performing all the science that we anticipated it to be able to yield. During the first few years, we are going to emphasize the thing that Hubble does well, today, with the aberration in it—ultraviolet, spectroscopy, photometry. We are going to take a replacement instrument up in 1993 which corrects the aberration and then is able to perform all the high resolution work in the visible that Hubble was anticipating doing.

Now, as you point out, this Hubble is designed as a 15-year program. The smartest thing we ever did was put this in shuttle orbit where it can be serviced by the Shuttle. If this was someplace else, geostationary orbit, what you see is what you get. But because it is in shuttle orbit and is designed to be fixed by the Shuttle, we go up with replacement instruments in a year or two or three from now and fix the telescope.

The CHAIRMAN. Can you clarify one more point? We talked about the flight which was in the original plan in 1993, I believe you testified to, and we would be bringing additional instrumentation up, second generation instrumentation. Now, the question is, has that instrumentation already been manufactured so it's going to cost us more money to modify that? What is the story on that?

Dr. FISK. The budget for the Hubble Space Telescope, which is in the 1991 budget, includes the development of the second generation wide field/planetary camera. It is a straightforward modification to the camera. Take a mirror out that's already there, put a new one in that corrects for the aberration. The only thing we're exploring now is, could we do it quicker? We were planning to do it in 1993, that was always the plan.

The question is, can we accelerate that? If we can accelerate it, it's undoubtedly going to cost more in the near term to do so. We're asking that question now of the project and the instrument builders as to how fast they could accelerate it. But, again, to emphasize the point, we have always anticipated changing the instruments on the Hubble Space Telescope. None of the instruments are designed to work for 15 years in orbit.

You may recall in early hearings all those wonderful discussions about latches. Remember the latch discussions that this committee had back in the early 1980s? Well, the idea of that was, how do you design a system that you can pull an instrument out in orbit and put a new one in and have it aligned properly in the telescope? A great amount of work has gone into that.

Astronauts have been trained in the pools down at JSC as to how to do that kind of replacement. All of that has been a part of the program since the telescope was designed, and it is that part of the program which is going to return the telescope to its full use.

The CHAIRMAN. The chair recognizes the distinguished gentleman from Pennsylvania, Mr. Walker.

Mr. WALKER. Thank you, Mr. Chairman.

First of all, Admiral Truly, I want to thank you for commenting briefly on the shuttle situation. I think I speak on behalf of most of my colleagues, if not all of us, when we say that we think you've been unfairly maligned for what you did on the shuttle in this same period. I mean, a lot of the press has indicated there's another failure there.

You did right. You pulled them back, and you made certain we're going to fly right with these rather than going ahead, despite the fact that the agency was under some fire, and I think you deserve to be commended for doing what was done on the shuttles, and that is something that, coming off the Challenger, we wanted you to change.

Admiral TRULY. Thank you very much for saying that, Mr. Walker. I appreciate it.

Mr. WALKER. Having said that, I do want to also say that, you know, we're rather frustrated by the Hubble.

The CHAIRMAN. That's referred to as a second shoe.

Mr. WALKER. Well, yes, the second shoe drops.

We're frustrated in part because I, for one, and I think probably most of the members of the committee at one point or another visited Hubble when it was sitting in California out in its specially prepared room, got the briefing on why we were spending $8 million a month to have Hubble there and stored, and one of the things that we kept hearing over and over again was, "Well, we're testing it, we're making certain everything is absolutely right on it, and there can be absolutely no doubt when we fly that everything has been gone through."

We find it frustrating, then, to come back later on and say, "Well, there were some tests that we could have been running but that we didn't do," for budgetary reasons or whatever, but the fact was that we kept being assured, and now the level of frustration is intensified by the fact that something wasn't done that could have been done during that long period of time.

So you have a committee that is just a bit skeptical based upon that. So let me go to the tests first. I understand that the end-to-end test that some people have referred to was largely a budgetary test that was one that probably Congress wasn't willing to pay for, in all honesty. But I also understand that there were some simpler tests that the agency decided not to do, and they decided not to do them, I gather, because you thought that everything was so good that there was no need to go ahead with the tests.

Is that in fact a fair characterization? If that is a fair characterization, does that indicate a change that needs to be made in attitude when we're dealing with these complex systems?

Admiral TRULY. Thank you, Mr. Walker. I think I would characterize it, from what I know and what I've learned in the last couple of weeks, as slightly different, and I'd like to, but let me assure that this also has been a frustrating, almost character-building two weeks for us. But let me talk about testing a little bit, and Dr. Fisk may want to correct me.

There has been a lot of discussion in the press about end-to-end testing. End-to-end testing on the Hubble Space Telescope had some major disadvantages.

The CHAIRMAN. Will the gentleman yield? I think you have to explain to the members what you mean by end-to-end testing.

Admiral TRULY. Essentially, in any program, an end-to-end test is when, after you have manufactured all the components and tested each of them, then you put the entire machine together, and you have what we call an all up verification that the system works together.

However, other than the cost of an end-to-end test, in the case of Hubble, as I understand it, the unbelievably tight specifications on the mirrors for the ultraviolet part of its mission made the project extremely wary of any large movement of the mirrors in tests like that that would have contaminated the mirrors. It's my understanding that contamination of hydrocarbons on the surface of the mirror to the depth of one molecule would have absolutely blurred the vision of the mirror in the ultraviolet part of the spectrum.

That is not in any way, however, to give you the impression that proper testing was done on the mirror. I think almost by definition this is going to turn out to be a case where, with hindsight, we can determine that a test could have been done that would not have had the potential of contaminating the mirror and would have found this aberration.

I think that's going to have to be a focus of Dr. Allen's investigation as to what were the circumstances that caused the program to test the mirror in such fine precision and yet not test it for a larger gross error in curvature that we see, and I say gross in a very relative sense, we're talking about measurements you cannot see with the human eye but are important in optics.

So in summary, I think if the decision came to me today, with what I've heard in the last two weeks, I would be very skeptical to order an end-to-end test. However, if the decision came to me today with regard to adequate testing for Hubble, I would say that whoever made those decisions in the past ended up with a testing sequence that had a flaw in it, because by definition it allowed this error to get through.

Mr. WALKER. Well, just to follow up briefly, was there a measure of overconfidence that led to that decision? Can we tell that at the present time?

Admiral TRULY. Could I ask Dr. Fisk to respond to that?

Dr. FISK. Let me make just a couple comments, if I may, even in answer to your previous question. You and I have both seen Hubble out at Lockheed. There was an enormous amount of testing being done on Hubble at that time, and in terms of the use of the fine guidance sensors, the data systems, the electronics, the through-put of how the instruments worked, they all received end-to-end test and obviously were successful. The telescope works fine.

The only time that you could have tested the mirrors together is in a sort of complete, how does this work if I put light on these mirrors?, was before you put it in the spacecraft, which would have been back in the 1983 or earlier time frame, when the mirrors were manufactured.

The test, however, was judged, and I think I agree from what I have seen over the last few weeks, to be the correct decision, to be one that was unlikely to tell you that the Hubble actually met its spec, because the spec was so rigorous and the test would have been so hard to do that it was really questionable as to whether technically you could have done that test and shown that Hubble met its spec, which is what you would have been asking, and there was a considerable risk of contamination.

Mr. WOLPE. Will the gentleman yield just for a moment?

Mr. WALKER. Sure, I'd be glad to.

Mr. WOLPE. I think your question is a really key question, but just to understand clearly then, so that the reason for not undertaking the test, from the agency standpoint, was for technical reasons not because of an absence of funding or for budgetary considerations?

Dr. FISK. To the best of my knowledge, and, you know, we're all learning the history of 1980 and 1981 when, you know, we're doing it by studying documents and talking to people who were there, that the decision was a technical decision. It was not a funding decision.

Mr. WALKER. Well, just to clarify, though, the end-to-end test, which has technical reasons, but it's also a couple of hundred million dollars, wasn't it, to do the test?

Dr. FISK. I don't know that we have a good cost number. Let me tell you what you would have had to do. You would have had to have built a test chamber which accommodated the size of the Hubble Space Telescope. You would have had to make it an extremely clean facility in order that you did not introduce any contaminations of hydrocarbons. You would have had to have characterized the test chamber to great accuracy, because let me give you the problem that you face.

Hubble's mirrors were built on what was called a "bed of nails," which was designed with great accuracy to compensate for gravity. In other words, to give Hubble the shape it would have in space. This was a very complicated and precise device. Now if I go put Hubble in its frame as it would have flown in space, I would not have that device, and so the mirrors would have sagged a little bit under gravity, and I would have to calculate what that sagging was in order to see what the test was going to tell me about the focus. That sagging turns out to be several wavelengths of light, and yet I'm looking to see that the focus is accurate to 1/20th the wavelength of light.

So the test is very difficult to perform as to see whether or not you would get the kind of focus that you want, that your spec said. So the reason was primarily technical. But, again, you know, by definition the testing program was not adequate. Otherwise, there would be no flaw. But you could have performed tests on the mirrors separately to reveal the problem that we have, and I think we will find that they were not performed.

The CHAIRMAN. Will the gentleman yield?

Mr. WALKER. Sure, I'd be glad to yield.

The CHAIRMAN. You know, I've kind of gone along with you up to that point. After all, we spent two billion bucks. It seems to me, and I think this is a legitimate question for a lay person to ask, we

spent the money, what did we build? It doesn't work. Now, the other question is, should we have tested it on the ground?

I'm not going to get into the details of the end-to-end test. If we could build the telescope mirror in the first place, then we sure as hell could build a way to test it.

Dr. FISK. I don't think there's any question about that.

The CHAIRMAN. Well, that's the key. That's the heart of it. And I think the question that the gentleman from Pennsylvania mentioned was, well, you know, how much would it cost? We've been reading in the press, and I don't have any fault with the press, they're asking a question, what do you think that chamber may cost, we know that in other areas in the use of mirrors of this type that there had been chambers built at considerably less, in fact less than $100 million, and I think we have to get to the point, because that's what the people are asking.

Who made the command decision not to test that mirror? That's the issue. And was that a wise decision to make? Would it have cost $300 million? Did we ever ask the Congress and say, "Hey, look, this is the heart of the whole telescope, the two mirrors, and therefore it will cost $182 million or $77 million to test it. Will you, Congress, give us the money because we think we ought to test that?" That wasn't specifically asked for any place that I'm aware of.

I think that's the heart of it, because, if the gentleman will indulge me further, I think that the whole idea when we had the hearings going back on the Challenger was the issue that emerged, was proper type of testing done as we go along? I applaud what Congressman Walker has said to the Admiral in, you know, grounding the two shuttles, vis-a-vis the point of view of the hydrogen leak. But I want to know and pin down why we didn't do the testing of the mirror. That's the key issue.

Dr. FISK. Please let me clarify that. The mirror was tested endlessly. Whenever you design a mirror and build a mirror, you build a device called the null corrector, which tests the mirror every time you do a grinding run.

The CHAIRMAN. Tell us what a null corrector is, for the record.

Dr. FISK. If you will bear with me, in the sense that what I know about optical systems I've learned in the last two weeks, so I will give you my knowledge of optical systems here. The mirrors on the Hubble Space Telescope are what are called hyperbolic mirrors. They have a shape like a hyperbole. They're not spherical; it's a more complicated shape.

So you create a device whose purpose is to essentially put a laser down on the mirrors in the shape that you want the mirrors to turn out to be, and that laser then bounces back off the mirrors, and you can compare the shape that you have the mirror in at that time with the shape that you expect, and that tells you what to do next to grind it.

The CHAIRMAN. It tells you in effect how to fabricate that?

Dr. FISK. That's right. It's a mechanical device whose purpose is to shine a laser surface——

The CHAIRMAN. Can we have one meeting here, gentlemen? We're having difficulty hearing the witnesses.

Dr. FISK. It is a device which shines a laser on the mirrors and therefore in the shape that you want the mirrors to turn out to be.

The CHAIRMAN. So when you say the null corrector, it is really the instrument that determines the correct construction and configuration of the——

Dr. FISK. Figure and surface of them.

The CHAIRMAN. And the surface, okay.

Mr. WALKER. So in this case, it was wrong, too.

Dr. FISK. Excuse me?

Mr. WALKER. In this case, it was wrong, too.

Dr. FISK. Well, let me get to the point here. The null corrector is a very simple device. It includes very few pieces of equipment—a few spherical mirrors which can be made to great accuracy, a known spacing between those mirrors; it is a very simple thing to make and to measure accurately. If you get an error in your mirror, the first thing you're going to look at is the null corrector, because it is the method by which you are specifying the shape of the mirror, the steps that you're going to take in the grinding, and the measures that you're making on the mirror every time you take a grinding step.

The null corrector exists for the Hubble mirrors. It was put in bonded storage after the program was completed in the early 1980s——

The CHAIRMAN. That was what was used to be able to design the mirror in the first place. That's available for review.

Dr. FISK. That is available. And we have, obviously, impounded that, and we are systematically looking at the null corrector to see whether there is an error in it, because that's certainly the first place you go and look when you build a spherical mirror. But, again, these are very straightforward devices to build, there was nothing unusual in the null corrector technology. It is the standard way to build large mirrors, and they are used because they are so simple to build.

Even though you are creating a complicated mirror pattern, the null corrector itself is made up of very precise elements which are easy to manufacture with great precision. So those kinds of measurements were routinely made on the Hubble, and in fact you may even see posters around town where you see the interference patterns which demonstrated how perfect the shape of the Hubble mirror was. Those interference patterns were generated by this null corrector.

Mr. WALKER. Well, I thank you for your indulgence, Mr. Chairman. I just have a couple more things.

We still haven't answered the question of whether or not there were some simpler tests that could have been done that should have been.

Dr. FISK. All right. I think the answer is going to have to turn out to be categorically yes, because the error involved is fairly large, and therefore some simple, low cost, no risk tests could have been performed on the mirrors which would have revealed an error of this size.

Mr. WALKER. To get back to my original point, why weren't those tests done?

Dr. FISK. We're all asking the same question, and we'll have to allow the Lew Allen panel to probe through the records as to how those decisions were made.

Mr. WALKER. You testified here a minute ago that there has been no dissent on the correction strategy that you propose. Is that within the agency, outside the agency? Is there no one that has come forward thus far and suggested that your correction strategy is a wrong strategy?

Dr. FISK. To my knowledge, there is no one. Let me give you the data. We, obviously, have a lot of optical experts who work on the Hubble Space Telescope who believe that this is a straightforward correction. We actually formed a separate panel, different from the Lew Allen panel, of outside optical experts to come in and, first of all, look at the spherical aberration data that we had just to confirm that they saw what we saw and to evaluate our fix to this problem.

They met last Thursday and Friday a week ago, they put out a statement, which I think was released publicly, and in that statement they confirmed that this is a simple, straightforward problem to correct, and that's the appropriate strategy.

Mr. WALKER. Just one final question. Do I understand correctly that all of the work that can be done on the correction can be done under present budgets, that there will be no additional costs involved with this?

Dr. FISK. The additional costs will come if we accelerate it, and there are a number of replacement instruments underway which were in the program anyway, some of which do not come on line until 1996. And we will ask the question, can we accelerate those activities?

Mr. WALKER. Well, the acceleration would cost additional money, but if you assume the same schedule, the correction to the aberration should not cost additional money?

Admiral TRULY. Assuming that what we've described as the hot trail that we're on and that Dr. Allen's group determines that that was the cause, and assuming that every one of the experts still agree with us that the correction will be as simple as it is, and assuming we don't accelerate it, we are budgeted to build those replacement instruments, and I don't see any reason why any significant cost would be added to the program to correct it.

Mr. WALKER. Thank you, Mr. Chairman.

The CHAIRMAN. The chair recognizes the distinguished gentleman from New York, Mr. Scheuer.

Mr. SCHEUER. I thank you, Mr. Chairman.

Admiral Truly, it's a great pleasure to have you back here again, and I've enjoyed your testimony, Dr. Fisk.

It fills me with dismay that we seem to meet, our paths seem to cross, every three or four years, Admiral Truly, in the wake of some horrendous space disaster. We last met in the investigation this committee held following the Challenger tragedy. Now we're meeting in another disaster, thank God not involving human life, but involving the hopes and expectations and the excitement of the entire American public, and you can deduce that we're all suffering from incredible frustration from let down, from dismay that this business could happen again.

It's a cause of utter consternation to me that I could hear words flowing from you two gentlemen that there was a simple, low cost, no risk test that could have been made—that's Dr. Fisk's testimony—that there was a recently discovered flaw, that the flaw was allowed to get through, that the testing sequence had a flaw. How could the testing sequence have a flaw, how could the flaw be allowed to get through, why wasn't it discovered earlier, and in the name of common sense, in the name of heaven, how could there be a simple, low cost, no risk test that escaped our attention?

It's mind-boggling that we're going through this same agonizing process now that we went through four years ago after the Challenger, and we haven't addressed two great problems: number one, how could the science fail, how could there be a flaw, and number two, what was there in the system that prevented that flaw from being identified very early in the game?

I know our science and technology is capable of the best. We have no peers. There's a genius in American science and technology that can hold its head high and look the Japanese and the Israelis and the West Germans in the eye, but somehow or other, in the event, it doesn't always work out that way, and I have to ask, how could it be that there was a simple, low cost, no risk test that wasn't made? How could the flaw exist? How could it be so long before it was discovered? What is wrong, one, with our science that the flaw could happen in the first place without being detected, and what is wrong with the system that we are following that failed to identify this flaw until after the bloody thing was up in the air and we had spent a billion and a half dollars?

Now, the Japanese are nowhere nearly as creative as we are in science and technology, but there's something about their system that works. They spend an awful long time in preparation, in planning, in consensus making, longer than we do, but once they go, once that yellow flashing amber light turns to green, they seem to move with flawless precision, mathematical precision, and they don't have any great genius in science that we don't have. You can compare our nobel laureates to theirs, and we're worlds ahead of them.

With the Israelis, when they embark on a military mission, it seems to proceed with flawless precision, mathematical precision. We seem to have lost that capacity. What is there about our science that leaves these flaws undetected, and what is it about our system that doesn't identify the flaws until way, way, way late in the game?

Admiral TRULY. Mr. Scheuer, thank you very much. First of all, let me say that you're asking the questions that we are asking as well. I would say that one thing that makes me able to say that a simple test would have discovered this is I have the benefit of hindsight. I now know that the mirror was perfectly ground smooth, but I now know that the curvature was wrong, and therefore, with hindsight, I can tell you that there were simple and non-destructive ways that we could have tested that mirror.

So you're asking the important questions that we're asking, also, and I don't have the answers this morning. I would only make one other comment, though. The Japanese, the Israelis, the Russians, the French, everybody in the space business has failures. This is a

risky, risky business. I personally think that we, on the long haul, have been more successful than any other nation, but this hearing is about one of our failures, and it happened a long time ago in a way that we don't understand, and we're trying to get to it.

Mr. SCHEUER. Thank you, Mr. Chairman.

The CHAIRMAN. Thank the gentleman.

Ladies and gentlemen, because of the number of people here this morning, I think we better keep ourselves to five minutes.

The chair recognizes the distinguished gentleman from Wisconsin, Mr. Sensenbrenner.

Mr. SENSENBRENNER. Thank you very much.

Admiral Truly, first of all, I would like to reiterate what Mr. Walker and others have said relative to the fact that I think you really got a bum rap relative to the grounding of the shuttle fleet. Your job is to make sure that when the shuttle goes up it is as safe as it can humanly be, and to send an unsafe shuttle up would be a tremendous let down to the Congress and the American public, not the least of which the astronauts who are on board, and I would hope that you don't get anymore cartoons for doing your job right.

Now, having said that, you also have testified that the manufacturer of the lenses in question did not meet the specifications that NASA set down when the contract was reached. Has there been any investigation into the liability of the manufacturer to at least help fix this up and pay for it?

Admiral TRULY. At this point, let me answer it in two different ways. It was our belief prior to discovering this aberration on orbit that the contractor had fully met the specifications. And since we have not come to the fault in that process that allowed this change to happen or this mistake to happen, we're going to have to reassess that question.

The contract, as Dr. Fisk mentioned earlier, is a cost-plus-fee contract. There is a portion of the award fee of about a little over $3 million that still could or could not be awarded to that contractor. It is for more than the mirror performance, however. The same contractor also made an instrument called a fine guidance sensor, and the assessment of that portion of the award fee has not been determined at this point.

Mr. SENSENBRENNER. Well, obviously, this will cost more than $3 million to fix, particularly if we accelerate the program and get a replacement lens up there earlier than the 1993 timeframe that you've been talking about, and I certainly would strongly encourage NASA to look at the liability of the contractor, and if it does exist, to take appropriate legal action.

The second question that I have is looking forward. I think there will be many of my colleagues that will be looking into the way this flaw escaped detection. I'd like to look forward. We have a number of other Great Observatories that NASA is planning to launch within the next decade. How are you going to change the testing sequence so that we don't have another major flaw like the one on the Hubble?

Dr. FISK. Let me deal with the one that is perhaps closest to Hubble in its design, and that's the Advanced X-Ray Astrophysics Facility, which also has mirrors in it. I should say as an aside, the Gamma Ray Observatory, which is the second of the Great Observ-

atories and goes in November, has no single optical system in it. You detect gamma rays in different ways than you do visible light and X-rays, so there isn't a single optical system in the Gamma Ray Observatory.

In AXAF, however, there is a single optical system, a set of mirrors. Now, it turns out that in the case of—and this decision was made long before we discovered the spherical aberration in Hubble—that to do an end-to-end test of a mirror system in X-rays is a very straightforward matter. You do not have the same contamination requirements, you do not have the same accuracy requirements that you did with the Hubble mirrors, and so in the budgets for AXAF which were submitted and approved by the Congress in Fiscal Year 1989, we are building a facility at the Marshall Space Flight Center which does an end-to-end optical system test of the AXAF mirrors.

Mr. SENSENBRENNER. Well, I'm not talking just about optical systems, because there are other systems that can fail, too, as we all know, and I believe that we've got to learn from our mistakes. The other Great Observatories are the next great test on whether we've done so or not, and it would be nice to learn from our mistakes before they're up there rather than afterwards.

Dr. FISK. Well, I'm sure we're going to learn something from the testing policy on Hubble here. Please be assured that we do an enormous amount of testing on our spacecraft, and the Great Observatories are no exception to that rule.

Mr. SENSENBRENNER. My time is up. Thank you.

The CHAIRMAN. I thank the distinguished gentleman.

The chair recognizes the distinguished gentlelady from Tennessee, Mrs. Lloyd.

Mrs. LLOYD. Thank you very much, Mr. Chairman.

Admiral Truly, Dr. Fisk, thank you for being with us this morning. As members of this committee, we've certainly shared in your pride and your successes and your accomplishments, and today we share as we look at the tragedies before us. Our Space Program has been very popular with the American people, but in this day of competing demands for our dollars, I must tell you as a member of this committee that the Space Program is indeed in jeopardy unless we can see the light at the end of the tunnel. Our Space Program could be about as popular as our Foreign Aid Program, so it is in the best interest, not in NASA, but this committee to realize our responsibilities.

In looking at the Hubble experience, is this a unique experience? Are there general lessons that could be learned, such as in servicing and repair done on the Shuttle? I know that some of the other large spacecraft programs will not be able to be serviced in this manner.

Admiral TRULY. I think certainly that we'll learn lessons at the top of NASA, at the management level, from this on attention that needs to be paid to the straightforward, simple questioning of test programs, as an example. In the case of Hubble, quite honestly, a lot of the problems in the Hubble that occurred during this same period of time have already been learned and factored into future programs. The management of the entire Hubble Space Telescope was totally taken hold of and changed in about 1983. Unfortunate-

ly, at that time, the error that we are talking about today had already occurred.

One final comment, I do think, as Dr. Fisk said and as you alluded to, that we're very fortunate that a spacecraft of this value is in the shuttle orbit, that we can get to it and retrieve the entire capability as quickly as we can.

Mrs. LLOYD. Well, another concern of mine that has been stated before is the management problems. Is our management structure partly to blame for not knowing this should have been done or this should have been test here? If we had had a single center management for the new programs, would this have improved the communication so we would have had a better hands-on testing program?

Dr. Fisk, would you address that?

Dr. FISK. In this case, I don't think that would have been an issue. The mirrors were entirely the responsibility and the optical assembly was entirely the responsibility of the Marshall Space Flight Center, and so there was a single center responsibility for this device, the optical system. The instruments that were being built on Hubble were managed by the Goddard Space Flight Center. And there were some interesting complexities of making the whole system work together, but this one single system for which we've discovered a flaw had a single center of management.

Mrs. LLOYD. But should we be looking at the management structure of NASA because we do have a such a varied array of management structure? Should we have more unity in the program?

Admiral TRULY. I keep saying this, and I don't want you to think that it's an excuse, but frankly the NASA of today—I've spent a lot of time in the last four years in management structures, and we completely redid the Space Shuttle management structure; we recently redid the Space Station management structure; the Hubble management structure, at the time this happened was 10 years ago, and it was redone in 1983 or so.

So all I can say is we spend a tremendous amount of time today in NASA looking at a particular project, and if a particular project can be best managed—and it's always best managed by the straightest line organization that you can find from me to the hardware.

Mrs. LLOYD. Well, I say this, Admiral Truly, because we share the responsibility as the authorizing committee. What can we do better? This is not a lesson in pointing fingers. We're here today to say what can we as a Congress help you do better? And this is the line of communication that must continue to be open.

Admiral TRULY. Well, frankly, one thing you can do, and I think you're doing it today, is hold a hearing like this so that I can get the facts on the table instead of read the facts in the newspaper that aren't facts. Your point a little earlier about the disappointment in the American people or the fact that the credibility problems that the Space Program has are well-taken. And it's been a frustrating couple of weeks, and I understand it.

I understand that the Shuttle problems may appear to be similar to the Hubble problems, but they're very much different. And this forum allows me to put on the table what we know about what we're doing with you, and this authorizing committee has been, frankly, a tremendous support to our programs over the years, and

I'm sorry to be here today bringing to you the facts about a small but fundamental error that has been so traumatic in Hubble.

Mrs. LLOYD. Thank you very much.

Admiral TRULY. Thank you.

The CHAIRMAN. The chair recognizes the distinguished gentleman from Florida, Mr. Lewis.

Mr. LEWIS. Thank you, Mr. Chairman.

Welcome, Admiral Truly. I guess when you shave in the morning you look and say you're a victim of your own successes, because you have certainly turned the NASA program around, and I have a concern, as you do and many others, that though we're disappointed that the Hubble cannot do everything that it was sent up there to do, can you tell us just what it can do? It's not a failure.

There are a lot of things that can be learned on the interim period, before the WFPC gets up there, and I would like to know can you have the new camera ready in the time frame that you have? Can you adjust the shuttle schedule to get up and replace the WFPC soon enough? And I'd also like to know just what can this telescope do up there, and what kind of scientific knowledge can we gain, and what percentage of the mission do you feel that it can perform?

Admiral TRULY. Let me speak very briefly and then let Dr. Fisk add on. By the time the Hubble Space Telescope mission is completed, we believe today that it will have done everything that we have said it would do. In the interim period, until we can get a new camera here, there are areas of the science that can be done, and even though a large percentage of the visible will not be done, that means that the rescheduling will allow a large additional percentage of the time go to these areas, e.g., ultraviolet, that can be accomplished.

Dr. FISK. Let me make one point here, that we have a certain chauvinism as humans in thinking that the most important radiation is visible light, because that's the radiation in which we see with our eyes. The universe does not share that chauvinism. The universe radiates in all types of radiation. It radiates in X-rays and gamma rays and ultraviolet and infrared and radio waves, and there's this very tiny little wavelength band called visible light that we can see on the ground. That's why we have all the Great Observatories, why we do gamma rays with GRO and AXAF in X-rays and SIRTF someday in infrared.

But the Hubble Space Telescope was designed to work in two types of radiation—visible light and ultraviolet radiation—and there's an enormous amount of information about the universe and ultraviolet radiation. As mentioned earlier, Hubble is a factor of 100 greater than any previous ultraviolet telescope as it is today with the aberration in it, and so what you're going to find are some very exciting discoveries coming out, at least in the ultraviolet, and other things that Hubble can do, but ultraviolet astronomy is a way to understand the universe.

Mr. LEWIS. Thank you.

As we get into more areas of space exploration, we're going to find that we're still going to have malfunctions, and I want to say to you, Admiral Truly, you said that you would fly them when

they're safe to fly, I congratulate you on your courage and maintaining the integrity of the shuttle flight system.

Thank you very much, Mr. Chairman.

Admiral TRULY. Thank you.

The CHAIRMAN. The chair recognizes the distinguished gentleman from Pennsylvania, Mr. Walgren.

Mr. WALGREN. Thank you, Mr. Chairman.

I wanted to ask Dr. Fisk, you said that as far as you know the question or the decision not to test, and I guess we've been talking end-to-end test, was a technical decision rather than a cost decision, and I guess the direction of my thoughts is that I hope that this evaluation will look very completely at cost, because in many ways that determines what we do, and there are those who believe that the low-balling of costs in a project such as this may have led to shortcuts that then prejudiced the project.

You say that tests of the mirror might have been very expensive because of the contamination problem and perhaps not been done because of the contamination problem, but in this instance, you could do a back-up test on the equipment that was used to test the mirror without any problems with contamination, and it would seem to me that when we're not going to do an end-to-end test, then other tests of the equipment used to manufacture the mirror start to make more sense.

In particular, would not there have been a very inexpensive test of this null lens corrector that was used to certify the mirror as meeting specifications?

Dr. FISK. I will give you as complete an answer as I have at the moment, but please bear in mind, you know, that the Allen panel is asking those very same questions about what tests in fact were done on the null corrector and how were they done, were they done correctly, were they done complete, et cetera.

It is somewhat difficult to actually do a test on the null corrector to calibrate it, but one could imagine, for example, there is a back-up mirror that was generated by Kodak, a different company, a different process. In principle, you could have put the Kodak mirror in the Perkin-Elmer under the null corrector and see how they compared. I mean, there is a simple test that could have been done. You have to ask why, and those are questions that the Lew Allen panel is asking at the moment as to those kinds of questions.

I want to be very careful here not to condemn the guilty before we've even heard the evidence here. There is a train that we're following, a logic that says if you made a mirror, you used the null corrector. If that's in error, that explains the problem. And then you say, well, if it's in error, why wasn't it tested? I mean, those are the chains that you go down. But we may discover that the null corrector was perfect. I mean, we may discover an entirely different cause of this problem, and we need to let that process go. I mean, the records exist, the equipment exists, even the people who did it are still around someplace working for other companies. And we're going out and interviewing them, and I'm sure we're going to be amazed, probably disappointed. Probably with the virtue of hindsight we'll say what it is that should have happened there.

Mr. WALGREN. Well, let me ask you this. Will your investigation go back to the original awarding of the contract? Because, as I un-

derstand it, some of the competing bids provided for more comprehensive testing of these mirrors than not, and it would be really a fundamental lesson to be learned if somehow or other this contract were awarded to Perkin-Elmer under circumstances that met an artificially low cost in order to get this project going.

There are those who believe that the Superconductor/Supercollider is going to come in way over cost and that we get to be committed to these projects by artificially low estimates of what they're going to be, and I hope that your investigation will look at the bid awarding process, because if it did turn out to be a dumb mistake that was simply not done, it will be the result of the way the bid was awarded as opposed to any technical actual mistakes.

Dr. FISK. If I may, we certainly will go back that far and look, but, please, there is some evidence and facts that are worth getting on the table relative to that as we speak. Each of the bidders had a different testing philosophy which was thoroughly evaluated and felt that the Perkin-Elmer one was inadequate. That may prove to have been a bad judgment, but there was no cost driver that I'm aware of that said these people are going to do more tests; therefore, we're not going to select them because they're more costly, and Perkin-Elmer is going to do something different.

The main deciding factor in the award of the bids was not the mirror. Remember, there are other things in this bid, including the Fine Guidance Sensors, which were believed to be the real technological driver on this, and Perkin-Elmer was chosen in large part because they were perceived as having a better design for the Fine Guidance Sensor.

This was all in a single bid package: Fine Guidance Sensors, optical structure, mirrors, et cetera. The testing or not testing of the mirrors was not, to the best of my knowledge, a deciding feature in the selection of the contractor. The mirrors were believed to be a relatively straightforward and known process for determining the shape of the mirror.

Mr. WALGREN. Thank you, Mr. Chairman.

Mr. NAGLE. Will the gentleman yield?

Mr. WALGREN. I'd be happy to yield.

Mr. NAGLE. Let me quote from the evaluation from one of your documents on the question the gentleman from Pennsylvania just asked you about the Perkin-Elmer approach. It says, "Our only concern about the Perkin-Elmer approach centers around their plan to utilize as an as yet unverified computer controlled mirror polishing technique." Now, I've been informed that in fact we cannot find where that unverified computer controlled technique was ever in fact verified.

Dr. FISK. No, I don't think that's a—let me tell you my understanding, and, again, please bear in mind that we're all learning the history of this thing. The computer mirror polishing worked fine. That's not the issue. That simply says, what instructions did you give to the little things that do the polishing, and you do it with a computer as opposed to by hand. But the instructions, of course, come from the measurements that you make with this null corrector.

If the computer controlled polishing hadn't worked, you wouldn't have gotten a mirror at all. You wouldn't have been able to do it to

the surface that you expect to achieve here. So that in the final analysis, that was not a weakness in the process. I'm sure we're not going to find it to have been a weakness in the process. The weakness in the process has got to have something to do with how you measured the surface of the mirror, which was a technique that is in common use by both bidders, the null corrector.

The CHAIRMAN. Well, the chair is going to call on the distinguished gentleman from Missouri, Mr. Buechner, but the chair has a question that's arising in his mind. It seems to me that the guy who built the null corrector, which tested the mirror, was the same guy that built the mirror, and it would seem to me that there was no outside independent check made.

So here a contract goes out and says you build a mirror, here's your null corrector design, this is what you do, that's going to help you build a mirror, and that's how you're going to test, but there's nobody else checking on me. Just think about that a minute.

The chair recognizes the distinguished gentleman from Missouri, Mr. Buechner.

Mr. BUECHNER. Dr. Fisk, you pointed out that we're getting some great ultraviolet tests, and you related the fact that humans are kind of chauvinists, and we like to, I guess, you know, it's the reason why we carry around pictures of children and grandchildren. We like to have something to look at. But I guess in that vein, that's what we as representatives of the American taxpayers are faced with the most dramatic problem, and that is I have yet to have one of my constituents say, "God, there are some great ultraviolet tests being taken out there."

You can't show them on television. People can't see the bang for their buck, and that leads us to the real problem that we have, and that is it took us a long time to make the steps back up from the fall from Challenger. And in this Congress there has always been a number of wolves who have circled the Space Program wanting to strip the financial flesh from it, and this wound that we've got again here is giving them renewed effort, and as we go back and we talk about taxes, our reduced spending, the big problem that I see from this is that we've got nothing that we can stimulate the people so that they talk to their representatives.

That's why whenever there is any kind of a test, whenever there is any result that you can show, it is vital that you get it out so that we can at least say that is not just a, you know, floating 15-cent one you get at a carnival made out of plastic type of little telescope.

But more importantly, I'd like to revisit the issue of liability. First, I'd like to know what do you expect the cost to be for the replacement mirror?

Dr. FISK. We're not going to make any attempt to replace the mirrors in the primary system. That's not a feasible approach and not necessary. We are going to modify in a very minor way one mirror, one little mirror, in the second generation instruments, the next Wide Field/Planetary Camera, to correct for the aberration which exists in the primary mirror. It's a straightforward correction of modest cost.

Mr. BUECHNER. How much?

Dr. FISK. I don't have a number. If you're talking about, you know, what even in space costs something less than $100,000, I don't know what number to assign, but it is not a big number. If we accelerate it, we're going to have a different profile that will cost some extra money, which we're going to look at.

Mr. BUECHNER. Who do you anticipate right now is going to pay for that?

Dr. FISK. I'm quite confident it will probably be you and me and the American people.

Mr. BUECHNER. Well, I know that there is not a 30-day warranty or a 15-year warranty that comes with this particular optic system, but it seems to me that, you know, in layman's terms, if you don't build it right in the first place that you ought to be picking up part of the tab. Now, I know there's a liability waiver, you share it compositely with the producer, on research and development, but you gave them specs, and they didn't meet the specs. That's not research and development.

That's not like telling them to build an atomic bomb, and however you build one, we don't know how. You gave them a set of specs. You may say that the rocket system may be a research and development mode, but if there is a component of it that, you know, this is how you build this section, and you give it to them, and they screw up on it, I think that's not research and development. It looks to me like they ought to be picking up a lion's share of this, instead of simply saying the taxpayers should pick it up.

Dr. FISK. Well, we will certainly explore those issues. I do not pretend to be either a contract lawyer or know what is available to us under contract law, but, I mean, what we do in R&D contracts is we do as everyone else in the Government does, and we will exercise every option we have here.

Admiral TRULY. I might say, though, that it will be easier to explore that issue after the panel has determined precisely what happened, when it happened, how it happened, and how they didn't catch it. Today, we're giving you the benefit of the data that we have today, and I think any further discussion on our part would just be pure speculation.

Mr. BUECHNER. Well, I just close that it just seems to me that if you gave them a formula that there is a different set of standards that should be applied to that under procurement than one in which you say, "Gee, we've never had any telescopic lens anywhere in the world, and therefore, you know, give us your best shot." In this case, we gave them a formula; if the evidence proves out that they didn't meet it, then I don't think they should be let off the hook, and that's just my opinion. I think the taxpayers of this Nation agree with me.

The CHAIRMAN. I thank the distinguished gentleman.

The next member and our colleague that I want to recognize has done a great deal of the background work on the Hubble Program going back over a number of years and is one of the most knowledgeable people on the committee on this issue, and the chair is pleased to recognize the distinguished gentleman from Missouri, Mr. Volkmer.

Mr. VOLKMER. Thank you very much, Mr. Chairman.

Dr. Fisk, I want to direct my questions to a few other things. At the present time, there are five instruments on the Hubble, correct? Not just the wide angle planetary camera.

Dr. FISK. That's correct.

Mr. VOLKMER. We had a faint object camera.

Dr. FISK. Right.

Mr. VOLKMER. Has that been tested?

Dr. FISK. We have taken pictures with the faint object camera, yes.

Mr. VOLKMER. All right. Now, at the time that all these instruments, these five instruments, were designed, they were to meet certain specifications to do certain things.

Dr. FISK. That's correct, yes.

Mr. VOLKMER. Now, how close to those specifications, since you've already tested the faint object camera, is it able to comply with those original specifications?

Dr. FISK. To the extent that we have checked everything out, everything is meeting spec. You should bear in mind that there is a dual checkout period that goes with the telescope: Orbital Verification 1, Orbital Verification 2. The Orbital Verification 1 is primarily the space craft; the orbital verification two is primarily the instruments getting ready for the science that is to occur. So there are additional checkouts to occur on the instruments, but we have seen nothing to date that suggests that the instruments are not working perfectly.

Mr. VOLKMER. All right. That, too, you're not able to use the visible on that as well as the wide field/planetary, correct?

Dr. FISK. The visible is degraded. Please let's not say we cannot use it.

Mr. VOLKMER. Well, it's degraded.

Dr. FISK. Excuse me?

Mr. VOLKMER. It's degraded.

Dr. FISK. It is degraded, that is correct. But, again, you know, we will be taking visible observations. One thing I need to make sure everybody knows here is that Hubble's ability to distinguish close objects meets spec. We can resolve bright objects which are separated by as little as ⅒th of an arc second.

Mr. VOLKMER. But you're not able under the faint object camera, under the visible, to do any better than you could do from one right here on earth?

Dr. FISK. It depends, sir, on what——

Mr. VOLKMER. That isn't what we intended the Hubble for.

Dr. FISK. I'm not going to diminish the fact that we have lost the capability—we have deferred, if you like—we have a difficulty with capability in the visible, but the Hubble image—please give me just a second here—the Hubble image is not the same as a blurry, ground based picture.

If you look through the atmosphere with a ground based telescope, most of the blur that you see has to do with atmospheric seeing, and you get a peak which is fairly broad at whatever the atmospheric transmission is. In the case of the Hubble, because of this distortion, we have a fairly broad background and a very narrow peak, which meets spec, less than ⅒th of an arc second. The energy in that peak was supposed to be 70 percent of the in-

coming signal. It's only about 20 percent because of the spread that occurred due to the distortion in the visible light.

But the peak is still there, and that piece of information in that peak gives you the prospect, the very real prospect, of deconvolving the signal to produce high resolution pictures of certain types of objects.

Mr. VOLKMER. But with the aberration, you are not able, just like on the wide field, you're not able to do what you planned to do or what was planned to do with the faint object camera, either, on the visible.

Dr. FISK. In the visible.

Mr. VOLKMER. In the visible, correct.

Dr. FISK. That's right.

Mr. VOLKMER. Now, have you tested out the faint object spectrograph?

Dr. FISK. I have to check the extent of the testing here. Not yet.

Mr. VOLKMER. I didn't think you had, but I just wanted to make sure.

Dr. FISK. That was a test, right?

Mr. VOLKMER. I don't believe you've checked it out yet to high resolution spectrograph.

Dr. PELLERIN. The instruments are turned on. We've been systematically walking through the turn-on, including high voltage supplies and so forth.

Mr. VOLKMER. But as far as it being able to meet the specifications, you can't answer that yet.

Dr. FISK. I can't answer yet, but, again, we have no reason to believe it will not from what we have seen so far.

Mr. VOLKMER. Well, I heard those stories when we talked about the mirror back several years ago, too. Not with you, but with others, so let's pass that for a minute. I would like to know when you have completed your test and also on the high speed photometer, also. Okay?

Now, Mr. Chairman, I know my time has run out. I have one more question that is pertinent to this. I think it's very pertinent to this whole thing.

The CHAIRMAN. The gentleman is recognized.

Mr. VOLKMER. This goes back to some testimony in 1983 by Mr. Rehnberg, who was Perkin-Elmer's vice president at the time, and you are talking now about the ultraviolet, because what you're telling us here today is we're going to be able to do the ultraviolet.

Dr. FISK. That's right.

Mr. VOLKMER. The question was, "Mr. Rehnberg, in your testimony, you state, 'In the ultraviolet regions of the spectrum, the primary mirror is marginally acceptable.' Could you elaborate on what you mean by marginally acceptable?" And the response was, "I described the primary mirror as marginally acceptable in ultraviolet because of particulate contamination known to be on the mirror's surface. The deleterious effects of dust particles are more severe at short wavelengths ultraviolet than long wavelengths visible and infrared.

"Analysis has shown that when faint stellar objects are viewed in the presence of very bright objects, the ultraviolet light scattered from dust particles will approximately equal the dark sky in

the background, thus just beginning to compromise the quality image. The mirror's reflectivity is essentially unchanged; it is the light scattered by those dust particles to form a higher background intensity that causes a problem. In the spectrum of visible and infrared regions, the effect of dust is much less noticeable."

Now, we have now said we're going to be able to do the ultraviolet. Have you been able to do the ultraviolet?

Dr. FISK. Well, two points you ought to know. The mirror was cleaned subsequent to that testing point.

Mr. VOLKMER. I understand that.

Dr. FISK. And that the measure of obscuration of the mirror is 1.6 percent, spec was less than 5 percent, and we have ultraviolet data. Yes, sir, we have measured in the ultraviolet.

Mr. VOLKMER. All right. Have we been able to meet the specifications on the FOC and the wide field in the ultraviolet?

Dr. FISK. This is Dr. Pellerin, who is the Director of Astrophysics.

Mr. VOLKMER. He's the one that said that we had already tested the faint object spectrograph.

Dr. PELLERIN. Well, the instruments are all in the checkout process.

Mr. VOLKMER. Pardon?

Dr. PELLERIN. The instruments are all in the checkout process, and there have been many tests performed on all of the instruments. It has been a major part of our program since we've launched. We've checked high voltage, detectors, dark currents, exposures; what we have not done, and I think was maybe the thrust of your question, is taken astronomical data with all the instrumentation.

Now, with regard to the ultraviolet capabilities, just a few days ago, we had ultraviolet light coming through one of the instruments, and I am told we have verified the ultraviolet transmission of the mirrors within spec at this time.

Mr. VOLKMER. On which camera?

Dr. PELLERIN. This was the high resolution spectrograph. It was not taking astronomical data, but it was seeing ultraviolet light coming down the barrel of the telescope. We have verified today the particulate contamination well below the requirement, and also the ultraviolet transmission of the mirror system is within spec.

Mr. VOLKMER. Thank you, Mr. Chairman. My time is up. If we go around again, I still have some more questions.

The CHAIRMAN. I thank the distinguished gentleman.

The chair recognizes the distinguished gentleman from Illinois, Mr. Bruce.

Mr. BRUCE. Admiral Truly, you and Dr. Fisk have indicated several times a risky business. "Risky, risky," in fact, you said one time. What's risky about fabrication of the mirrors, fabrication of the architecture for the computers, the telemetry involved? It seems to me that a lot of things that you've done many times before and now assembled and sent up in a space telescope, but, individually, there's nothing risky about anything that was involved, was there?

Admiral TRULY. This particular mirror where the area is is a—I don't want to subtract from the precision and the state-of-the-art requirements that we placed on the contractor to make it. On the

other hand, I don't want to subtract from the point I made earlier that we expected the contractor to make this mirror not only to the proper smoothness, but to the proper curvature.

I'm not an optical expert, so I can't really comment on the technical risks. I personally believe that the failure here, from my point of view, with hindsight, was to do not only a precision test that was done throughout the grinding of the mirror to make sure it was smooth, but a more gross test to make sure that the curvature was proper.

Mr. BRUCE. But there wasn't anything risky about that. What I'm trying to find out is what was the risk that we took as taxpayers in putting up the telescope?

Admiral TRULY. Well, I said technical risk. I believe that a country that builds a telescope that weighs, I think, over 20,000 pounds, takes it from the surface of the earth with all the instruments and controls and things that go into it, and puts in orbit above the earth over 300 miles to take data from the universe incurs a great amount of programmatic and technical risk to put all that together.

My point was to just point out that we're in a business where those technical risks are there. I'm not trying to in any way downplay the accountability or the disappointment we have that this error was made, but it is a lot of risk to be in a business where you have to bring so many things together with so much precision and operate in such a hostile environment before you know whether or not you have achieved it or not.

Dr. FISK. If I can just add one thing, I mean, please bear in mind that there are aspects of the Hubble Space Telescope, its pointing stability, for example, which are far beyond what anyone has ever done before. The ability to point the Hubble Space Telescope with 7/100th arc second precision over many hours is something which was a challenge, a very large challenge, and one which works very well.

I mean, there are parts of this technological risk that we took. I mean, the Hubble images would also be blurry if that telescope didn't point with the stability that was required, and that would have been a failure we would be here explaining, but that's not a problem. It does point. That risk was met.

Mr. BRUCE. If it was a risky business, then, and you've now appointed the Allen group to study when the mistake was made and how the mistake was made, will they also be involved with how to keep this sort of mistake from creeping into the process again in a risky business?

Admiral TRULY. I think that undoubtedly when Dr. Allen has completed his investigation and has looked at the issues of what happened, when it happened, why didn't we catch it, and makes recommendations from lessons learned from that, in that way he will certainly be involved in taking technical risk out of future endeavors like this.

Mr. BRUCE. Is that part of his present charge?

Admiral TRULY. His charge is to lead the team to find out what happened and make recommendations. We have not constrained him in any way in what recommendations or how far he would go, and I believe he'll be testifying here after us.

Mr. BRUCE. I thank the chairman.

The CHAIRMAN. I thank the gentleman.

The chair will recognize the distinguished gentleman from Connecticut, Mr. Shays.

Mr. SHAYS. Thank you, Mr. Chairman.

It strikes me that we have four observatories; one is to do the X-rays, one is the gamma rays, and one is the infrared, but this was the visible, and it strikes me that what we have found is that the visible isn't working, and so, Admiral, your comment that we're learning all these other great things, the primary reason why we have this observatory up there, we're not being able to utilize that primary reason. Is that correct?

Admiral TRULY. The most visible of the Hubble Space Telescope's capabilities is the one that is damaged, and, frankly, from a point of——

Mr. SHAYS. That's not my question. My question is, is the primary reason for this to be there in the visible?

Dr. FISK. No. You know, Hubble and any project of this size has many motivations. If you asked an astronomer how would he make fundamental discoveries on the universe, he'd say——

Mr. SHAYS. I'm not going to say that there aren't other benefits from this. I'm really asking a very simple question. I only have five minutes. Was the primary reason for launching this observatory the visible? Was that the primary reason?

Dr. FISK. I would say it was equal between visible and ultraviolet. I don't know how to answer your question except to say——

Mr. SHAYS. If that's your answer, okay. So it isn't just the visible, it's the ultraviolet?

Dr. FISK. Absolutely.

Mr. SHAYS. Okay. In terms of the five instruments that ultimately will be replaced, will they all be replaced at the same time, or will they be replaced in stages?

Dr. FISK. The current plan is to replace in stages. You know, that's again something that has to be revisited, but, fortunately, the instrument which will be ready first is the instrument which is most impacted by the spherical aberration, which is the Wide Field/Planetary Camera.

Mr. SHAYS. Two of the five are primary visible, correct?

Dr. FISK. That's correct.

Mr. SHAYS. And will those be the first two to be replaced?

Dr. FISK. The faint object camera, which comes from the Europeans, does not have at this point in time a replacement. They did not design a replacement instrument.

Mr. SHAYS. So it's not really entirely accurate to say that there's no additional costs, that we were going to replace all these five. You mean the fact is we have to replace all five, we don't know precisely when that's going to happen, we don't even maybe know in a general way, and there's one that wasn't even planned to be replaced.

Dr. FISK. Allow me to clarify that, though. There is in our plans, as opposed to the European plans, a replacement instrument which performs the same function as the faint object camera, and the question is, could that be made earlier? We, obviously, in the original plans anticipated that the Europeans with their FOC, their

Faint Object Camera, would have a clean run on the telescope here for some years, and then we would bring along a replacement instrument, which is in our plans. Again, it's a question of whether we're going to accelerate that in some way. Please bear in mind their camera works very well in the ultraviolet.

Mr. SHAYS. I hope ultimately we learn during the course of this hearing when all five will be replaced, what time schedule, because it seems to me that it's not going to happen by 1991 or 1992 or 1993, it's going to happen much further on.

Dr. FISK. The replacement of all of them at this point in time is much further on. That is correct.

Mr. SHAYS. And during that time, during that 15-year period that this observatory will be functioning, we are not going to be able to take advantage of the primary reason or at least a 50 percent reason why this instrument is in space.

Dr. FISK. No. Please bear in mind that the principal instrument in the visible was the wide field/planetary camera, and it's the one which is designed to be replaced no later than 1993. That's the principle visible instrument. So when you make that replacement and make the correction for the aberration, most of what you wanted to do in visible light is available to you again.

Mr. SHAYS. Just this last question. The manufacturer happens to be right in my district or right next door, a lot of the employees, and I'm not looking from a personal standpoint to have the manufacturer be held liable, but the fact is it strikes me whoever the manufacturer is, if they've been given something that is supposed to be done to specs and it is not done to specs, they would have to be held liable.

I guess the analogy, and I want to know if this analogy is wrong, with my eyeglasses. If I am given a certain prescription and they don't make it to that prescription, it's their cost, not mine. Is that a proper analogy? Where's the fault in it?

Admiral TRULY. I think you make a good point, and that's the reason we need to allow Dr. Allen to go to the bottom of this and find out where the error was made. We're premature in targeting what the fault was until we really know. At the present time, we have checked the mathematics and believe that the prescription was proper.

Mr. SHAYS. So you believe it, but we don't know.

Admiral TRULY. But the investigation is not concluded.

Mr. SHAYS. Thank you, Mr. Chairman.

The CHAIRMAN. I thank the distinguished gentleman.

The chair recognizes the distinguished gentleman from Iowa, Mr. Nagle.

Mr. NAGLE. I'm not going to ask you about the visibility problems, I think other members of the committee have covered that adequately, but just so I understand where I'm at, in addition to the visibility problems, I earlier read your contract language about Perkin-Elmer's computerized mirror polishing technique that was not verified. The agency assured itself that the alternative techniques that were proposed could be verified, but I to date have no evidence that in fact that concern was ever pursued.

But in addition to that, if I understand where I'm at, we have a misprogramming in the pointing system that causes the telescope

to look in the opposite direction, we have a cable blocking the rotation of the antenna that has seriously limited the rotation of the antenna, we have a failure to fully evaluate the day/night affect of the solar rays to produce a permanent jitter in the telescope that reduces observing time, and then I learned that we also have a problem with the radiation belts, because the HST project has been reported to me that certain electronic elements, the telescope's control and data systems, have been paralyzed or falsely activated by exposure to the penetrating radiation in the South Atlantic anomaly where the earth's inner radiation belt comes to its lowest altitude.

The existence of this radiation belt at that level has been known since 1958, and my first question is, is that in fact happening? Has the telescope been partially paralyzed or falsely activated by exposure to these belts?

Dr. FISK. The answer is no. Let's make sure we're all together on this thing. The South Atlantic anomaly in the Van Allen belts has been known for a long time, it's known to the Hubble Space Telescope people, and we had originally thought when we designed this project that we wouldn't even be able to operate in it. We would have to turn the telescope off. The instruments were sensitive, and the instruments would experience difficulty in this. We couldn't even take observations. It would make it very difficult to make observations.

What we have discovered on orbit is we can operate through the South Atlantic anomaly, that's the good news, but we see some single event upsets in the electronics when we do, and it has a very simple correction which has been implemented, and that is to increase the readout from the hard memory, which is not affected by this, into the soft memory, which is affected by this, and do it more frequently than the single event upsets occurred, end of problem.

Mr. NAGLE. Let me——

Dr. FISK. Just so we don't get confused here anyplace, all of the things that you listed there, antenna pointing issues, day/night jitters, those are problems that are either behind us in their entirety or they are problems that the fix is known and is being implemented now. We are not working any other issue on the Hubble Space Telescope besides the mirror aberration which we view will degrade its performance.

Mr. NAGLE. The cable blocking the antenna, however, does reduce the range of the telescope's ability to observe, does it not?

Dr. FISK. No, it does not, actually. There are two high gain antennas on the Hubble Space Telescope. One of them experiences a cable blocking for about 10 percent of its ability to point, and the correction is a very straightforward one—don't dump data when that antenna has to be in that pointing attitude, dump it at some other time. There is no impact on observing time.

Mr. NAGLE. You're telling me that the cable and antennas are up to specifications?

Dr. FISK. Am I telling you what?

Mr. NAGLE. They're up to specifications as was originally designed?

Dr. FISK. The observing time is not implicated by this. That's up to specifications.

Mr. NAGLE. Are they up to all the specifications NASA had when it was originally designed? Some of them are, some of them aren't?

Dr. FISK. If you're asking me does the antenna point in the range that it should up to specification, the answer is no. There's a 10 percent blockage. Is that an impact on the performance of the telescope? The answer is no.

Mr. NAGLE. Now, I'd like to read you a statement and ask you to comment on it, and I apologize for its length, and I'll read it as quickly as possible.

An astronomical telescope in low earth orbit is subject to massive operational complexities due to thermal cycling, target selection, and an intermediate transmission of data and commands.

On the other hand, an observatory in its geosynchronous orbit, such as that used for the predecessor of the HST, a very successful IUE, is free of most of these complexities as well as the susceptibility to interference by penetrating radiation. In fact, a telescope in such orbit can obtain at least three times as much observing time as can one in low earth orbit. In other words, it could do as much observing in one year as would require three years below orbit.

Mr. Chairman, could I have an additional minute?

The CHAIRMAN. Yes.

Mr. NAGLE [continuing]:

The decision to put the HST into low earth orbit was heavily influenced by the hope that the telescope could be serviced or man-tended by the shuttle. There is some basis for such hope, for the very existence of such examples of such retrieval, repair and replacement of parts established that these on-orbit procedures are massively expensive and require heroic and life-threatening activities by astronauts. Also, the unreliability of the shuttle scheduling may cause extended delays.

For these various reasons, the Director of the Space Telescope Science Institute, Dr. Ricardo Giocanni, argues that it would be much more cost effective to scrap the man-tending concept in favor of a progressive series of advanced telescopes launched at, say, five-year intervals into geosynchronous orbit. Also, he favors the use of unmanned launch vehicles for this purpose.

Based on your experience in looking into the future, what is your reaction to Giocanni's point of view?

Dr. FISK. I haven't asked Ricardo about that, but I'm sure he thinks that was one of the dumbest statements he ever made, because the Hubble Space Telescope with spherical aberration in geostationary orbit is inaccessible to you, and you could not fix it. The Hubble Space Telescope with spherical aberration in shuttle orbit is fixable.

Mr. NAGLE. Well, if you put it up there right to begin with, you wouldn't have to worry about fixing it, though, would you?

Dr. FISK. I'd like to guarantee you that we always do things correctly, but I also like to know that if something does go wrong that it's a repairable problem and that the investment that we've made in Hubble Space Telescope can be realized.

Mr. NAGLE. Then the decision to launch the UTE to geosynchronous orbit was an error?

Dr. FISK. IUE?

Mr. NAGLE. IUE.

Dr. FISK. Well, of course, the investment in IUE was very small compared to the investment in the Hubble Space Telescope. When you do a billion and a half dollar project, it is nice to know that you can make sure that it will work. IUE, as I recall, was probably about a $60 million or $70 million spacecraft.

Mr. NAGLE. My time has expired.

The CHAIRMAN. The chair recognizes the distinguished gentleman from California, Mr. Mineta.

Mr. MINETA. Thank you very much, Mr. Chairman. I want to congratulate you and thank you for having these hearings, because all of us were disappointed by what's happened here, but I'd like to take another track, if I might.

First of all, you say that you have assurances that the contract specifications were met. What about the specifications themselves? Have they been checked in terms of what was our goal? Given these specifications, were they really the correct specifications to get us to what we were going to be doing?

Dr. FISK. To the best of my knowledge, the specifications were correct. This is a very straightforward telescope assembly, one that's well known. The formulas are easy to derive. We have checked them again, and we believe they're accurate, but let me tell you why you should feel some comfort in that.

The formulas for the mirror were shared with everybody who built an instrument. Everybody who had to build an instrument to work with those mirrors received a copy of the prescriptions and, of course, designed their instruments to work against that. So over the course of this project, literally hundreds of people have poured over those design formulas in the course of doing their job on the Hubble Space Telescope.

Mr. MINETA. Let me ask, how many cameras are there in the Wide Field/Planetary Camera?

Dr. FISK. Four.[1]

Mr. MINETA. And were all four checked end-to-end?

Dr. FISK. As you may be alluding to here, the first thing we thought was there was an error in the WF/PC camera, not in the primary mirror. That was the thing that people thought first, because it was so difficult to imagine that there was this kind of error in the primary system, and so the kinds of checks that have been done, of course, is to use each of the Wide Field/Planetary Cameras separately and to take pictures with the FOC, with the Faint Object Camera, to convince ourselves that it was not an instrument, it was in fact in the telescope assembly itself.

Mr. MINETA. But if each of those cameras has a mirror, and from an earlier question I got the impression you were indicating there was only one mirror——

Dr. FISK. No, there's only one, to the best of my knowledge, that needs to be replaced to correct the aberration. There are many different mirrors in the Wide Field/Planetary Camera.

Mr. MINETA. Well, I guess there are going to be endless questions about the flaw, why did it not get detected, all these other things, and we're going to have Dr. Allen's group taking a look at this, you're taking a look at this, but, frankly, there's something else I'd like to just point out. It's probably more of a statement at this point than it is a question.

I have been absolutely I guess dismayed at the position of the National Space Council. For a group that's supposed to be in concert with the goals of the United States of America in terms of

[1] Subsequent information submitted by NASA corrects the number four to the number eight.

space and planetary exploration, to me, this group has been doing nothing constructive but has been trashing NASA. There has been enough trashing of NASA, and it seems to me it ought not to be coming from the National Space Council. They ought to be asking for the resources and other kinds—whether the resources be human or money—to help NASA out at this point, and I'm not hearing that. I hear the same kind of drivel coming from the press about what's happening at NASA.

Now, frankly, I think the reason they're doing it is because the National Space Council is Defense Department-oriented; they would just as soon do NASA in and take over the programs over to the Department of Defense, and I think we on this committee ought to watch this very carefully, because, to me, NASA is a civil space agency, and it ought to be preserved as that.

Whether it's the Hubble Space Telescope or any other program that you have going, I don't want to see these things become DOD projects, and so, Mr. Chairman, under your very careful monitoring, I know that you will protect our jurisdiction as a civil space agency, but I just wanted to make this point at this time. Thank you very much, Mr. Chairman.

The CHAIRMAN. I thank the distinguished gentleman from California, and may I reassure him under every circumstance that there will not be a take over of our civilian space program by DOD.

The gentleman from Alabama, Mr. Browder, is recognized.

Mr. BROWDER. Thank you, Mr. Chairman.

Dr. Fisk, we understand that there were two lenses used in the program—a refractive lens and a reflective lens. Briefly, could you tell me what those were used for?

Dr. FISK. I will give you my knowledge of this thing, which is, again, rudimentary. There are two ways to make a null corrector. One is called a refractor, one is called a reflector. Reflectors are more accurate. The refracting lens was therefore used in an early part of the polishing exercise to get the mirror relatively in a gross sense. The reflecting lens was used later in the processing part to produce the more accurate figure.

I understand that the refractor was also used in the measuring of what is called essentially the radius of curvature of the mirror as opposed to the actual figure of the mirror in detail.

Mr. BROWDER. Was there ever a discrepancy in measurements taken with these two lenses?

Dr. FISK. I don't know the answer to that question. It is a question that has been raised, and perhaps we need to address that more to Dr. Allen's panel, but I'm aware that one of the exercises they are performing is to see this data, go back and find the data from the two different null correctors, and ask when they were taken and what did they show, but at this point in time, I have no knowledge of whether they were in discrepancy, whether that discrepancy, if it existed, was large in the sense that the mirror is of the error that we see or was it just the kind of discrepancies that you would expect from two different measuring techniques, but clearly that is a question that we expect the Allen panel to pursue.

Mr. BROWDER. Well, that is a question that we have, and we would like to know whether that should cause concerns for us about the way that this was carried out. A second question, and I

hope I'm not covering territory that's already been covered, why did NASA decide not to include in its solicitation a requirement to perform a final full assembly test?

Dr. FISK. Let me just summarize the discussion on that point that was carried on earlier. In order to conduct such an end-to-end optical system test, it was a technically very difficult test to do, because you can never simulate the optical assembly system as it exists in space. You have to allow for gravity, which tends to cause the mirror to sag, you have to allow for the collimation of light. Stars are infinity, your sources are finite.

You have to make those corrections, and the Hubble Space Telescope was being built to accuracy unheard of in any other optical system, and the project made the judgment that the test was technically very difficult to achieve and ran certain real risks. Remember, Hubble had to be protected against contamination at all costs.

The CHAIRMAN. Will the gentleman yield?

Mr. BROWDER. Yes.

The CHAIRMAN. Well, you're coming to the nub of the issue, which I think ought to get on the record, although we want to get on with the rest of the witnesses. The fact remains we have lay people who are the Executive Branch and the Legislative Branch making decisions not of a technical nature, and it seems to me, as the committee understands it, there were two primary bids. One came in from Kodak, as I understand it, and Kodak's bid included a testing of the facility, where the Perkin-Elmer contract did not.

Now, logic would say that one—well, we have a test in one and not in the other, and somebody had to make a decision on some basis to select the Perkin-Elmer bid over the Kodak bid, even though the Kodak bid did include the testing. Now, logic would tell us one of two things. Either one of those bids, one must have been better than the other from a technical point of view, at least someone assumed that, and the second leg of that journey, if the gentleman would yield further, is the cost factor.

So here I have a decision, I'm the representative of NASA, and somebody's got to make that decision. I have an opportunity for one lens that would include a testing as part of it, that seems to me to be pretty much up there that I'd look at, I have another lens I can get, but I'm not going to get that one tested, that's not included, and then I don't know what was the difference in cost, so there had to be a technical decision made, and there had to be a cost decision made, I would assume.

Will the gentleman continue to yield on that point?

Mr. BROWDER. Yes, of course.

Dr. FISK. To the best of my knowledge, the decision to choose between the two contractors was chosen by other things that were in the bid. Remember this was a bid for mirrors, it was a bid for a metering truss, it was a bid for Fine Guidance Sensors; I mean, the mirrors weren't even the majority of the work, but they were relatively about a third of the work.

And so the decision to decide which contractor to go with was based to the best of my knowledge of the public's documents on what we call mission suitability; that is to say the things that they were going to provide and the deciding factors were probably the Fine Guidance Sensors, not the mirrors themselves.

Now, there was nothing, however, to prevent NASA from once having chosen Perkin-Elmer to require that end-to-end test. The fact that they didn't bid it is not the deciding factor.

The CHAIRMAN. It didn't mean that they couldn't include it later on.

Dr. FISK. That's right. You could have said, "Look, I've chosen this contractor because I believe overall they are going to perform all the things that I want, but I like this thing from the other bid," and I could say, "Okay, I'm going to require that they do that." So a conscious decision was evidently made by the project at the time of the selection of bid that the Perkin-Elmer testing policy—and they had a testing policy which was reviewed—was adequate without that end-to-end test.

The CHAIRMAN. The gentleman from Alabama?

Mr. BROWDER. Mr. Chairman, let me pursue that just one minute. You've identified the difficulty of the testing and the cost of the testing. Which one was the primary consideration, the difficulty of doing that testing or the cost?

Dr. FISK. To my knowledge, the primary decision on not doing the test was for technical reasons, that the test was extremely complicated, it was questionable whether or not it would have yielded the information you wanted, which was does Hubble meet spec, and ran a serious risk of contaminating the mirrors in ultraviolet.

Mr. WALGREN. Will the gentleman yield?

Mr. BROWDER. Yes.

Mr. WALGREN. This is an interesting point to me, because when you're dealing with mirrors, something is the mirror image of what you're ultimately producing, and if the decision to not test the actual mirror itself was a valid one on technical grounds, that leaves you the mirror image of whatever it was, and in this case the mechanism that was used to test the mirror, that could be evaluated. It strikes me that there might have been a very simple oversight in this instance that led us not to evaluate the mirror image of the mirror, which would have been as good as evaluating the mirror.

I hope that you will pursue the awarding of this bid and the mechanisms within it, because, as I understand it, in the background of all this is companies desiring to get experience in mirror manufacture for later military contracts which were to be let, and given the fact that Perkin-Elmer may have been very desirous of that business, it seems important to really look at why the contract was let to one company as opposed to another, and I just hope that that fits with the point the gentleman was making.

I thank the gentleman for yielding.

Mr. BROWDER. Thank you, Mr. Chairman.

Mr. VOLKMER. Mr. Chairman, would you yield just on that a minute?

Maybe you could elaborate on it a little more. In the fine guidance system and the instrumentation for the mirror and everything, isn't it true that Perkin-Elmer was far out way ahead in background experience than Kodak was?

Dr. FISK. That is correct, sir.

Mr. VOLKMER. Wasn't it true that basically the contract was let because of that and not to Kodak because of those things?

Dr. FISK. That's my understanding, yes.

Mr. VOLKMER. Okay.

The CHAIRMAN. All right. This, I think, is a good time for us to take a break. I know this is taking a little bit longer, but we want to be thorough in our work, and I want to thank the two witnesses we have had all morning for their participation and their help in this inquiry.

When we return—we'll go and vote and return immediately. It's an amendment to the Jacobs amendment that eliminates staffing for former presidents, in case anybody is getting ready to go out. I ask the members to come back right away so we can continue with our work, and we'll call up Dr. Lew Allen and panel two when we return. So we'll return, say, in 10 minutes.

[Whereupon, at 12:18, the committee recessed, to reconvene at 12:30 p.m., the same day.]

AFTERNOON SESSION

The CHAIRMAN. The committee will come to order.

When we broke up for our vote a few minutes ago, we decided that we would then proceed to hear from Dr. Lew Allen on our panel two, who is the Director of the Jet Propulsion Laboratory in the National Aeronautics and Space Administration, and he comes to us with high credentials and high respect.

So therefore, without further ado, Dr. Allen, you're recognized to make your observations that you may wish. It might be well that you might want to get on the record the breadth and scope that you see your responsibility to be as chairman of the review panel, and then if we have some questions to ask, we will follow up on that.

The chair recognizes the distinguished gentleman.

STATEMENT OF DR. LEW ALLEN, DIRECTOR, JET PROPULSION LABORATORY, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, PASADENA, CA

Dr. ALLEN. Thank you. I have prepared a brief statement which I would like to submit for the record.

The CHAIRMAN. Yes, fine. No objection, so ordered.

Dr. ALLEN. First of all, I'd like to add to that statement, if I may, an event that has occurred since writing it, and that is that the European Space Agency has asked to be represented during the investigation, and we have therefore added as an observer a Mr. Lawrance of the European Space Agency who then will participate with us as an observer.

The CHAIRMAN. Could you elucidate just a little bit on that, Lew, in the sense that why would they be interested and what their participation is?

Dr. ALLEN. Yes. They're responsible for the Faint Object Camera, and as a result they are very interested in the total scope of the investigation; that is, those that lead to corrections of instruments, because it will involve their instrument eventually, and secondly, I think they have a justifiable concern about what happened and want to be informed.

The CHAIRMAN. For the record, they're participants in the program, and therefore your plan is to have them join with you on an observer level or a participant level?

Dr. ALLEN. That's correct, yes, sir.

The CHAIRMAN. Okay.

Dr. ALLEN. The charter of my board is to look at three issues: that is, when did the problem arise, at what stage during manufacture did this problem occur?; how did it arise, what was the mistake that was made?; and why wasn't the problem detected before launch? Now, that charter is deliberately narrow in that respect. We are a technical group, we are looking at what happened and when and why we didn't find it.

Questions came up during the earlier testimony as to whether our conclusions will be in the form of management recommendations. We are not tasked to do that; however, I believe that our examination of the facts will be presented in a manner which will allow NASA to reach certain management conclusions. So we are in no sense excluding that from our responsibilities, but it is not our direct objective.

I would like to, with your permission, Mr. Chairman, to go directly to explain to you the avenues of the investigation that we are pursuing and why and what our expectations are, and I'd like to, before going into those, make a general observation which really applies to everything I say. At the present time, there is a train of logic which leads us down a particular path as to the elements that are most in question and where we think it most likely that the problem occurred.

There are reasons for that, but it could be wrong. Therefore, what I will describe to you is what we are doing with regard to those most probable sources of error, but we are not overlooking the less probable ones, and we are also investigating those but at somewhat lower priorities. So I wish to describe to you this main line of investigation.

As you've heard, the on-orbit data implicates the primary. There are observations which have been made in orbit which, while not entirely conclusive, are very strongly indicative of the problem being entirely in the primary, and if not entirely in the primary, primarily in the primary mirrors. However, that's a very important point to determine unambiguously, because it affects how the subsequent corrections will be made.

Therefore, one of our earliest attempts at investigation is to absolve the secondary mirror if it's possible to do that. A second secondary was made by Perkin-Elmer to nearly the same quality as the flight model, and that secondary exists in bonded storage. We will review the manufacturing history of that mirror and understand what independent checks were made during its manufacture, if any, and our present plan is to ship that second secondary to Lawrence Livermore Laboratory, which has an ability to do a coordinate measurement of that mirror to sufficient accuracy to determine its shape with enough accuracy to absolve the mirror if it's not the main cause of the problem.

That total line of investigation will, we hope, not take more than a few weeks, maybe as many as six, and then we'll be able to clari-

fy whether or not the secondary is a major contributor to what we're seeing.

Now, you've heard something about this, but I'll review it a little bit. The primary was tested during manufacture and certified for flight using this device that is called a null corrector. And if there were an error in that corrector, and it is, a small error would be sufficient.

Dr. ALLEN. Now, it would cause the primary to be configured wrong and then to be certified for flight in error. That corrector exists in its original form in the set-up that it was used to actually test the mirror and as far as we know has been untouched since its use in testing the flight mirror.

Therefore, we have impounded that, are allowing no actions to be taken with regard to that set-up that would damage the integrity of the set-up as being as it was during the flight test, and we are doing those examinations that could be done without disturbing it and then are examining a series of tests that we can do with it to find out whether or not there is an error in it.

Now, there was another null corrector that was made, and those two correctors were compared. Our rough understanding is that they were compared, and a difference was found between the two; however, since the refractive-null corrector was never designed for purpose of measuring the shape, it was considered to be inaccurate, and those results were not of a concern.

We are reviewing the data from both of the tests of those null correctors and comparing them to determine the validity of that conclusion and reviewing the records that exist of the management process that was gone through to make that determination to put the total reliance on the reflective null corrector.

Now, there was a third null corrector, and that was manufactured by Kodak and was used in the manufacturing of the back-up mirror. That mirror and corrector exist. We're not sure of the integrity of that corrector, but the mirror was delivered to Perkin-Elmer and exists, and, again, we can provide cross-checks. That is, we can test the Eastman Kodak mirror with the Perkin-Elmer null corrector, and if there was a problem with the Perkin-Elmer corrector, that should reveal it. That's a more time-consuming test than we would like but will be one that we will examine carefully.

There was an earlier 60-inch demonstration mirror made by Perkin-Elmer in preparation for the Hubble process which we believe used the same null corrector that was later used for the flight mirror, and, once again, one can do some simple tests on that 60-inch mirror, such as what is called a knife-edge test, to verify the shape of that, and that may reveal whether or not there was an error in the null corrector.

So the point that I wish to make is that we have a set of components and a lot of data and records, which should provide us with an adequate basis for determining the source of the error. If we are lucky, we will be able to determine that perhaps from examining the data rather quickly, but some of the tests are rather time-consuming, and so if we have to go into the more time-consuming tests, the results of our investigation could take several months, perhaps as many as six for some of these more complicated tests.

Our process at the present time is to look at that data very carefully, to interview the individuals who are responsible for those tests, and try to find the error that way, to look at each of these components and test apparatus and determine the quickest and most meaningful of the tests that will, by cross-checking, determine whether that error exists in the null corrector.

We are confident that we have the ability to find the error. The time we're not so certain about. We, to date, are having complete cooperation from the contractor and the project office in working to find this error. We are conducting the investigation with due diligence in the sense that the data has all been impounded, the equipment has been impounded, access to the equipment and to the data is allowed only under the supervision of an independent Government person or a representative of our Board, and only under procedures that I approve, as the Board chairman.

We know that the most likely outcome of our investigation is going to be a result which is very embarrassing to someone or some group, but nevertheless we will find the cause, and we will present the facts as we determine them.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Allen follows:]

STATEMENT OF

DR. LEW ALLEN, CHAIRMAN

HUBBLE SPACE TELESCOPE OPTICAL SYSTEMS BOARD OF INVESTIGATION

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

UNITED STATES HOUSE OF REPRESENTATIVES

JULY 13, 1990

MR. CHAIRMAN AND DISTINGUISHED MEMBERS OF THE COMMITTEE:

I APPRECIATE THE OPPORTUNITY TO TESTIFY BEFORE YOUR COMMITTEE AND TO SHARE WITH YOU THE PROGRESS AND PLANS OF THE HUBBLE SPACE TELESCOPE OPTICAL SYSTEMS BOARD OF INVESTIGATION.

AS YOU KNOW, I WAS ASKED BY DR. LENNARD FISK, NASA'S ASSOCIATE ADMINISTRATOR FOR THE OFFICE OF SPACE SCIENCE AND APPLICATIONS, TO CHAIR THIS REVIEW BOARD SHORTLY AFTER NASA LEARNED OF THE PROBLEM WITH THE HUBBLE SPACE TELESCOPE'S MIRRORS. THE BOARD IS CHARTERED TO LOOK AT THREE ISSUES: WHEN DID THE PROBLEM ARISE, HOW DID IT ARISE, AND WHY WASN'T THE PROBLEM DETECTED BEFORE LAUNCH? THE INVESTIGATION WILL CENTER AROUND THE OPTICAL TELESCOPE ASSEMBLY (OTA) AND WILL NOT CONCERN ITSELF WITH THE SCIENTIFIC INSTRUMENTS ON BOARD THE TELESCOPE. THE BOARD WILL EVALUATE THE FACTS AND CIRCUMSTANCES SURROUNDING ALL STAGES OF THE OTA'S DESIGN, CONSTRUCTION, TESTING AND EVALUATION , AND WILL ALSO ADDRESS ANY POTENTIAL CIVILIAN OR MILITARY ALTERNATIVE TESTING PROCEDURES THAT MAY HAVE BEEN ABLE TO DETECT THE ANOMALY.

THE BOARD CONSISTS OF MYSELF, J. ROGER P. ANGEL, JOHN D. MANGUS, GEORGE A. RODNEY, ROBERT R. SHANNON, AND CHARLES P. SPOELHOF. I AM THE DIRECTOR OF THE JET PROPULSION LABORATORY (JPL), A NASA FACILITY MANAGED AND OPERATED BY THE CALIFORNIA INSTITUTE OF TECHNOLOGY. IN THE PAST, I HAVE SERVED AS CHIEF OF STAFF OF THE AIR FORCE AND AS DIRECTOR OF THE NATIONAL SECURITY AGENCY. PROF. ANGEL IS A PROFESSOR OF ASTRONOMY AND OPTICAL SCIENCES AND AN ASTRONOMER AT THE STEWARD OBSERVATORY AT THE UNIVERSITY OF ARIZONA. MR. MANGUS IS

HEAD OF THE OPTICS BRANCH, SPACE TECHNOLOGY DIVISION AT NASA'S GODDARD SPACE FLIGHT CENTER. MR. RODNEY IS ASSOCIATE ADMINISTRATOR OF NASA'S OFFICE OF SAFETY AND MISSION QUALITY AND WAS FORMERLY DIRECTOR OF MISSION SUCCESS AT THE MARTIN-MARIETTA ORLANDO AEROSPACE COMPANY. PROF. SHANNON IS A PROFESSOR OF OPTICAL SCIENCES AND THE DIRECTOR OF THE OPTICAL SCIENCES CENTER AT THE UNIVERSITY OF ARIZONA. MR. SPOELHOF IS THE RETIRED VICE PRESIDENT AND DIRECTOR OF TECHNOLOGY ASSESSMENT FOR COMMERCIAL AND INFORMATION SYSTEMS FOR THE EASTMAN KODAK COMPANY. THESE PEOPLE ARE WORLD-RENOWNED AUTHORITIES IN THE FIELDS OF OPTICAL SYSTEMS AND SPACECRAFT QUALITY ASSURANCE, AND I HAVE THE HIGHEST CONFIDENCE IN THEIR ABILITIES AND EXPERTISE. SARAH KEEGAN, THE NASA PUBLIC AFFAIRS OFFICER, AND GARY TESCH, THE NASA DEPUTY GENERAL COUNSEL, WILL SUPPORT THE BOARD AS PUBLIC AFFAIRS ADVISOR AND COUNSEL, RESPECTIVELY.

EACH MEMBER OF THE BOARD HAS HAD SOME INVOLVEMENT IN THE HST PROGRAM AS WELL AS WITH MANY OTHER OPTICAL PROGRAMS BOTH GROUND- AND SPACE-BASED. HOWEVER, THE CURRENT AND PRIOR INVOLVEMENT OF THE MEMBERS HAS BEEN SUCH THAT WE ARE ABLE TO RENDER UNBIASED AND INDEPENDENT ASSESSMENTS OF THE PROBLEM. EACH MEMBER HAS MADE FULL FINANCIAL DISCLOSURES AND HAS BEEN SWORN AS A SPECIAL GOVERNMENT EMPLOYEE. DR. FISK HAS INSTRUCTED US TO DETERMINE THE FACTS FULLY AND IMPARTIALLY AND I AM CONFIDENT THAT WE WILL DO SO.

AT THE PRESENT TIME, ALL OF THE RELEVANT DATA AND EQUIPMENT HAVE BEEN IMPOUNDED. ACCESS TO THE IMPOUNDED ITEMS IS AUTHORIZED ONLY BY MY BOARD AND OCCURS UNDER SUPERVISION OF A GOVERNMENT OFFICIAL.

THE FIRST MEETING OF THE BOARD OF INVESTIGATION WAS HELD LAST WEEK IN WASHINGTON D.C. THE GOAL OF THIS MEETING WAS TO INTERVIEW THE PEOPLE WHO WERE INVOLVED WITH TESTING AND MANUFACTURING THE MIRRORS.

FROM THE PRELIMINARY EXAMINATION OF THE ON-BOARD DATA, THE BEST GUESS AS TO THE SOURCE OF THE PROBLEM IS SPHERICAL ABERRATION OF THE OPTICAL TELESCOPE ASSEMBLY. THERE IS ALSO A POSSIBILITY THAT BOTH COMA AND ASTIGMATISM MAY BE PRESENT BUT THIS CONCLUSION IS OBSCURED BY THE MAGNITUDE OF THE SPHERICAL ABERRATION. THE BOARD FEELS THAT COMA AND ASTIGMATISM CAN BE CORRECTED IF THEIR PRESENCE IS CONFIRMED.

REGARDING THE POSSIBLE SOURCES OF SPHERICAL ABERRATION, THE BOARD FEELS THAT THE MOST LIKELY CANDIDATE IS THE OTA (OPTICAL TELESCOPE ASSEMBLY) AND NOT ANY OF THE INSTRUMENTS ATTACHED TO THE OTA.

PRESENTLY THE PANEL IS EXAMINING THE MOST PROBABLE SOURCES OF ERROR AND IS ALSO LOOKING AT THE SEQUENCE OF EVENTS IN THE MANUFACTURING AND TESTING OF THE MIRRORS. ALTHOUGH THERE ARE MANY POSSIBLE SOURCES OF ERROR, SOME HAVE ALREADY BEEN DEEMED UNLIKELY. FOR EXAMPLE, IT IS HIGHLY UNLIKELY THAT THE SPHERICAL ABERRATION COULD HAVE BEEN CAUSED BY THE TRANSITION FROM THE EARTH'S GRAVITY FIELD TO THE GRAVITY-FREE ENVIRONMENT IN SPACE. FURTHERMORE, IT IS EQUALLY UNLIKELY THAT MATERIAL CHANGES CAUSED THE ERROR; THAT IS

CHANGES THAT WOULD OCCUR IN GOING FROM 1 G TO ZERO G OR EFFECTS DUE TO THE PASSAGE OF TIME.

THE INITIAL RESULTS SUGGEST THAT THE ERROR IS MORE LIKELY IN THE PRIMARY MIRROR RATHER THAN IN THE SECONDARY. EARLY TESTIMONY ALSO INDICATES THAT IT IS HIGHLY IMPROBABLE THAT THE ERROR IS IN THE PRESCRIPTION FOR THE MIRRORS; THAT IS, THE EQUATION DESCRIBING THE SHAPE. SUBSEQUENT INVESTIGATIONS BY THE BOARD WILL EXAMINE THE TESTING OF BOTH PRIMARY AND SECONDARY MIRRORS.

THERE HAS BEEN A GOOD DEAL OF DISCUSSION AND COMMENT IN THE PRESS ABOUT THE VERY HIGH COST ($100 MILLION HAS BEEN SUGGESTED) OF AN INDEPENDENT CHARACTERIZATION AND TEST FACILITY. THIS NEEDS SOME CLARIFICATION. THE PROJECT AND CONTRACTOR PERSONNEL DECIDED AGAINST PERFORMING SUCH TESTS BECAUSE THEY WOULD HAVE HAD TO HAVE BEEN EXTREMELY PRECISE (WHICH TRANSLATES INTO EXPENSIVE) IN ORDER TO MEASURE THE FULL ACCURACY OF THE PRIMARY MIRROR. ON THE OTHER HAND, USING RELATIVELY SIMPLE AND INEXPENSIVE CHARACTERIZATION TECHNIQUES, THE ABERRATION THAT, APPARENTLY, ACTUALLY EXISTS WOULD HAVE BEEN DETECTED.

IT IS NOT CERTAIN YET WHAT HAPPENED, OR WHEN IT HAPPENED, BUT I SHALL KEEP YOU INFORMED OF THE BOARD'S INVESTIGATIONS AS WE PROCEED.

I THINK IT WOULD BE APPROPRIATE AT THIS POINT TO MENTION A SEPARATE BUT RELATED EFFORT SET UP BY THE MARSHALL SPACE FLIGHT CENTER PROJECT OFFICE. THIS GROUP OF HIGHLY-RESPECTED OPTICAL EXPERTS IS CHARTERED TO LOOK INTO THE FLIGHT DATA THAT HAS ALREADY BEEN RECEIVED AND TO DETERMINE WHAT ADDITIONAL FLIGHT DATA IS REQUIRED. THEIR OBJECTIVE IS PRIMARILY ASSOCIATED WITH FUTURE PLANS OF THE

HUBBLE PROGRAM. THIS OPTICAL GROUP IS IN CLOSE CONTACT WITH MY BOARD AND WILL KEEP US INFORMED OF THEIR PROGRESS.

THERE REMAINS MUCH TO REVIEW AND MUCH WORK TO BE DONE. WE ANTICIPATE PROCEEDING WITH ALL DISPATCH CONSISTENT WITH THE TESTING WHICH WILL BE REQUIRED. WE WILL THOROUGHLY EXAMINE EVERY ASPECT OF THE SITUATION, AND REACH CONCLUSIONS BASED ON THE FACTS. AT THE MOMENT, THERE ARE NO DEFINITIVE RESULTS I CAN REPORT TO YOU; HOWEVER, I WOULD BE HAPPY TO APPEAR BEFORE YOUR COMMITTEE AT A LATER TIME TO SHARE OUR FINDINGS WITH YOU AS THEY BECOME AVAILABLE.

I WILL NOW BE HAPPY TO ENTERTAIN QUESTIONS.

The CHAIRMAN. I thank you very much.

Let me just get clarified for the record. The charter that you have been assigned to work under in effect says when the error may have happened, how the error may have happened—I'm paraphrasing what you said—and why not discovered sooner, and that's basically your charge.

Dr. ALLEN. Yes, sir.

The CHAIRMAN. Well, do you think that charge goes far enough?

Dr. ALLEN. Yes, sir. I believe that there are a number of aspects of examining the total problem. For example, coincident with our investigation is another investigation consisting of another group of optical experts who are examining all of the flight data with the purpose of determining the proper measurements to be made with the Hubble telescope in orbit from here on forward and the best corrective measures to apply to the instruments.

We are in close contact with that group, and they're sharing our views, but they are separate avenues, as they have separate objectives. I don't think there's any question but at the conclusion of our investigation, there will be a very strong desire on the part of NASA to look at all of the management implications of what we have to say.

The CHAIRMAN. Well, if the gentleman will yield, that's where I'm coming from. A number of observers have speculated that the root cause of the Hubble problem was that of cost estimates were understated, testing was cut back, and what started as a major technical challenge became a formidable management challenge.

Now, you're saying that in an ancillary point of view your group will look at that, but you don't consider that to be a charge of the group.

Dr. ALLEN. No, sir. Our job is to find the facts. Certainly, I will present those facts to Dr. Fisk and Admiral Truly——

The CHAIRMAN. If I can make a point, if we go ahead and we study it, we do want to know when it happened, we want to know how it happened, and we want to know why it wasn't discovered sooner, but so what? So we learn that; if we don't apply it back into institutional structures and the other areas, what have we learned? We know there's an error already.

Let me be the devil's advocate. We know that there's an error made already, at least that's what's been testified to, of some kind. It is, of course, very important to find out why and how it happened so it doesn't occur again, but what does that mean? I mean, do we then come back to the contractors and say, "You have made an error, you didn't do it according to the specifications; therefore, you have some liability involved here?"

Do we say that people are in the decision-making pattern at the time when the errors are being developed and built? Well, okay, half of them are gone now, I guess. Two-thirds of them are gone. I mean, what are we going to determine that—we know there was an error. How is it going to help us to determine there was an error? How is that going to help the NASA program?

You see, if we're down to the narrow point of saying when, how, and why not—what do you call it?—when it was discovered, why didn't we discover it faster, or whatever, what is that going to tell

us? That's simply going to tell us it happened, it's going to give us more specific data as to when and how. So what?

Dr. ALLEN. Obviously, the point you're making is exactly correct. That must be the total outcome of all of these investigations, how to improve the management structure, how to improve the technical approach so this will not happen again.

The CHAIRMAN. But that's not your direct charge, you're saying?

Dr. ALLEN. That's correct. But what I'm trying to distinguish is that I formed a Board which consists of, for the most part, optical experts; that is, people whose expertise is in how you manufacture telescopes, how you test telescopes, and who have had experience in the fabrication of many telescopes for various purposes. With this Board, we're going to determine the facts. I will present those facts in a forum to Dr. Fisk and Admiral Truly which will lead to management recommendations, but it's not this Board's primary responsibility.

The CHAIRMAN. That's what I want to get on the record. In other words, it's a very narrow charge—and, of course, there's nothing here personal—it's a very narrow charge, it's to determine what happened, when it happened, and why wasn't it devised sooner, so that's the total charge, but that really doesn't get back into any broader interpretation. Do you think we should have more of an in-depth investigation into all the peripheral relationships in management and so forth?

Dr. ALLEN. I believe the first thing is to find the facts. I think we need to find what happened, where it happened, and why it wasn't discovered before launch. I think at that point, then, clearly, one has to go in and ask broader questions of management, technical approach, contractual procedures, all of those. We will have those as far as facts go in our report, but the conclusions should be reached after we get those facts on the table.

The CHAIRMAN. The chair recognizes Mr. Walker, our ranking member from Pennsylvania.

Mr. WALKER. Thank you, Mr. Chairman.

I just want to figure out how narrow your charge is. I think you're telling us that it's pretty closed, and that concerns me to some extent. Are you going to be able to look at other situations related to Hubble that might be regarded as anomalies as a part of your investigation?

Dr. ALLEN. No, our investigation is of the flaw in the optical telescope assembly as we've seen it on orbit.

Mr. WALKER. For example, just after deployment of the telescope, as I understand it, there was an incorrect command that was relayed to the telescope to close the protective door, and it's my understanding that the door was designed to open only once, and as I understand it, they have figured out a way to bypass that now so that they think that this isn't going to cause a problem, but nevertheless that could have totally jeopardized the mission with an incorrect command.

So there may be some other problems that are in the whole scenario with Hubble, and you're telling us that you won't have any charge at all to look into those?

Dr. ALLEN. No, sir, I'm looking into the flaw in the telescope.

Mr. WALKER. Thank you, Mr. Chairman.

The CHAIRMAN. The chair recognizes the distinguished gentleman from Pennsylvania, Mr. Walgren.

Mr. WALGREN. Thank you, Mr. Chairman, and I only, I think, could touch on the same point that the chairman raised and also the gentleman from Pennsylvania, and that is the narrowness of the charge here. I guess my concern is, and I think it's shared by others, there is the danger that we get an investigation and that if the investigation is so narrowly drawn, we don't get at any root problems that provide us with a real correction in the way we're operating as a Government or as an agency.

In fact, the investigation, to the degree that it is strictly technical in nature, becomes almost a stocking horse for what NASA ought to do in terms of looking broadly at this problem, and I guess the value of these hearings, Mr. Chairman, is that maybe we can underscore on the record that obviously there is concern about broader problems than just that and that there are more facts to be found than just the technical facts.

My concern is that when we get your report, it will be a good, solid technical report that will reveal what went wrong, but it won't reach the facts that need to be found about the underlying decisions that caused that technical problem to occur. Would you concur with that?

Dr. ALLEN. I don't want to make too strong a point of all this, and, really, you probably should ask some of these questions of Admiral Truly as to how he plans to reach the final conclusions, but I would say the following thing. First of all, our charter is narrow. It is to find the facts related to this particular problem.

The CHAIRMAN. Is there a written charter? If the gentleman would yield, is there a written charter?

Dr. ALLEN. Yes, sir.

The CHAIRMAN. Would you make that available for the committee?

Mr. ALLEN. Yes, sir, I'd be glad to do that. It's very simple, however. It is just what I've said.

The CHAIRMAN. It's in writing, though?

Dr. ALLEN. Yes, sir.

The reason for that, I believe, is, number one, that was the plan. There is a Hubble Telescope Contingency Plan that if a failure occurs in Hubble, a particular plan is implemented, and the first thing to do is to investigate that failure and find out where it happened.

Now, I'd make another point. I would like to believe that Admiral Truly selected me to chair this and selected, for example, George Rodney, the Associate Administrator in Safety and Quality Assurance, to be on this Board because he will expect us, separately from the technical aspect of the report, to comment to him on the management aspects; that is, what can we do better, how can we improve NASA overall so these kinds of things don't occur?

Mr. WALGREN. So you will submit a separate range of conclusions that will comment on the general practices so that it will not again recur?

Dr. ALLEN. I believe that Admiral Truly will expect at least myself and Mr. Rodney to present to him our views that go more broadly than the——

Mr. WALGREN. Well, we certainly would appreciate that as well.

The CHAIRMAN. Will the gentleman yield?

Mr. WALGREN. Yes.

The CHAIRMAN. First of all, let me make the point that the charter will be inserted in the record at this point in the testimony.

[The charter of Dr. Lew Allen's investigation review board follows:]

NASA
National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of SPS

JUL 2 1990

TO: Director, Jet Propulsion Laboratory
ATTN: Dr. Lew Allen

FROM: S/Associate Administrator for Space Science and Applications

SUBJECT: Establishment of Hubble Space Telescope Optical Systems Board of Investigation

In accordance with the Hubble Space Telescope (HST) Contingency Plan dated 2/15/90, the Office of Space Science and Applications is establishing a "Hubble Space Telescope Optical Systems Board of Investigation." I am hereby appointing you to serve as the Chairman of that Board. It is our intent to establish a board whose members, primarily from outside NASA, are world renowned in the field of optical systems and spacecraft quality control. This Board of Investigation will be a working group charged to review, analyze, and evaluate the facts and circumstances regarding the manufacture, development and testing of the Optical Telescope Assembly.

Your charge as Board Chairman is to determine how and when the problems in the Optical Telescope Assembly (OTA) occurred, thereby leading to the observed spherical aberration, and how this aberration could go undetected prior to launch. The group will report the results of their evaluation to the Associate Administrator for Space Science and Applications. This group is not established to render, advise, or make recommendations.

This operational working group is an exception to the provisions of the Federal Advisory Committee Act. There is no requirement for public notice as to meetings or to have such meetings open to the public.

The immediate point of contact at NASA Headquarters for information, assistance and support will be the Director, Astrophysics Division, Dr. Charles Pellerin. He can be reached at 202/453-1437 (office) or 202/488-1423 residence).

Again, I want to convey my appreciation for your willingness to chair this board. Your leadership of this group will be instrumental in assuring a systematic review of the HST Optical Systems.

L. A. Fisk

L. A. Fisk

CONCURRENCE:

George Rodney
Associate Administrator for
Safety and Mission Quality

cc:
A/Adm Truly
AD/Mr. Thompson
G/Mr. Frankel
S/Mr. Diaz
Mr. Alexander
Mr. Rhome
Ms. Schmoll
SPS/Ms. Phillips
SZ/Dr. Pellerin
L/Mr. Kress
P/Mr. Sheehan
X/Mr. Pedersen
Q/Mr. Rodney

The CHAIRMAN. I think that the issue—this panel has high regard for you, you know that, over the years for the great work you've done, but I think that as we've been trying to narrow down the issues involved, and I think we did that well in the first three hours of this hearing, I don't think we should be misled, and that's not your misleading anybody, but the so-called study and review that's going to be made is extremely narrow from what I can see here, and in effect, the gentleman from Pennsylvania is pointing out, we're only going to be looking at the purely technical aspect of it, not at a broader picture.

What puzzles us on that approach is that when we looked at the Challenger accident, as you well remember, we looked at a very, very broad scoping under that charter to really assimilate what the whole process was institutionally and so forth and so on, which was extremely valid. Now, the question, if the gentleman would continue to yield, that I want to ask, do you think that Admiral Truly's charge to you is broad enough, I mean in formality, to say, hey, we've really got to look at this whole thing?

It isn't just the question that the mirror doesn't work; we know that now. It's the question of not just why it doesn't work, how it doesn't work, I would hope out of this review we would say our whole testing procedures need review. I mean, we're concerned now that the charge isn't broad enough.

The gentleman from Pennsylvania?

Mr. WALGREN. Thank you, Mr. Chairman.

In fact, your last characterization of the third point in your charge, why didn't we find it, could actually lead you very broadly. If in fact, as you say, you're going to find something—in your words—that is "very embarrassing" to somebody or some entity, that would indicate that something wasn't done that was obvious should have been done, and we know people don't make deliberate mistakes, and if it was not a deliberate mistake, then, obviously, people were in a position where the right questions were not asked or were not raised, and in order to answer the question why didn't we find it, you're going to have to evaluate why those questions were not raised.

Dr. ALLEN. Yes, sir, we'll do that.

Mr. WALGREN. Well, we certainly encourage you in that, and I do feel that we ought to, particularly as NASA is involved, be asking ourselves very broad questions. When the ranking minority member of this committee says that part of the problem here lies in the Congress not providing the necessary support, clearly, we ought to be asking how we are entering into these projects in the first place and are we entering them with the necessary support, and that goes to every project that NASA conducts, from the Space Station to the Shuttle itself and projects like this. So we may at least get a chance to get at something fundamental for NASA that might be helpful for future projects.

Dr. ALLEN. Absolutely. But I do agree with the philosophy which says we ought to find the facts first. I hope we can do that quickly and then draw the broader review.

The CHAIRMAN. If the gentleman will yield again, we are assuming at the beginning that the facts have to do specifically and only with the mirror and the testing and so forth. The facts are only the

results of the decision-making process, so the committee is very much interested in a broader approach to the entire issue, if I make my point.

Dr. WALGREN. I yield back the balance of my time, Mr. Chairman.

The CHAIRMAN. The chair recognizes the distinguished gentleman from Missouri, Mr. Buechner.

Mr. BUECHNER. Dr. Allen, you said that the corrector lens, your understanding is that they've been impounded, and they are in a position where they can be evaluated without anybody else in the intermediate period of time looking at them. Is that correct?

Dr. ALLEN. Yes, sir.

Mr. BUECHNER. What about the computer code that was used to generate the mirror-grinding instructions for Perkin-Elmer?

Dr. ALLEN. We have asked that all of that data and relevant information be impounded. It's all been put in a locked room, and no one is allowed access to that without approval of a plan and under Government supervision.

Mr. BUECHNER. Is part of your charge, the way you interpret it, that you will be able to critique the testing philosophy that was used in Hubble?

Dr. ALLEN. Yes, sir.

Mr. BUECHNER. I guess you were in the room when Dr. Fisk was answering questions. I asked the question about who was going to pay for the necessity to go up and to make the corrections and to replace. Earlier, we were told that NASA has a joint liability situation on research and development. Since you have optics people there, no one is asking you to be a procurement expert or a legal expert. But I would hope that somewhere in your findings, that if you find that there was simply an inability to properly follow the formula for the grinding of the lens, that it was somebody just made a mistake on that, that you would mention in your report that it was just an error in meeting the formula.

The reason I raise that is because, you know, as we're trying to figure out what went wrong, obviously, we want it to be as simple as possible, but I don't want to see it get comingled in with the object of the research and development format of going into space. Do you see where I'm coming from on this?

Dr. ALLEN. We will find the facts and identify how they occurred.

Mr. BUECHNER. All right. One other question, as we go back to the original properties here, was the Kodak test equipment, the original ones, is that still available? Do you know?

Dr. ALLEN. Yes. It was not in the original impounding, because we impounded all of the equipment at Perkin-Elmer, which included the Kodak mirror that was made. We have since verified that the corrector still exists at Kodak and have now impounded it. I don't know the full status of it, I mean, whether it's been used in any way in the interim, which might have changed it somewhat, but in any event, as it exists at Kodak now, it's impounded.

Mr. BUECHNER. Some of the critique of the program over the years has been that there was a constant underestimation of costs. And I know that you've heard it alluded to here that possibly, in response to that, that maybe there were some shortcuts taken, some tests not given, because of the worry about the costs that had

already been incurred. Are you going to address the whole issue of response to costs in your study?

Dr. ALLEN. Yes, sir, although I will say that based on what I know now, I would agree with Dr. Fisk's interpretation of that. That is, costs were a big problem. They mostly arose after the primary mirror was completed; that is, the big shake-up in terms of management and addressing the overrun and all occurred in 1983, and the mirror was actually finished in the latter part of 1981 or early 1982.

I think that I agree with Dr. Fisk that, as far as I can tell from looking back at the record, the primary basis for the decisions that were made, which may have been erroneous, but they were made at the time based on technical judgments, not on cost.

Mr. BUECHNER. One last thing for you to remember, and I think that Congressman Walker raised it originally, that probably most of the members of this committee at one time or another visited Lockheed in California while it was in sort of its mothball stage, and I remember specifically asking the same questions that Congressman Walker did about, you know, while it's out here, what's going on? And the party line at that time was, "well, you know, it gives us the opportunity to keep doing testings."

But I got the inference at that time that they felt that there were some things that had been done so many times that there was just a redundancy, and I guess the saddest thing is that sometimes you do not see the forest for the trees, and I guess that's what happened here. But keep in mind that a lot of us were told over the years that there was almost a constant testing going on, and I'd like to find out who it was and what they were testing. Thank you.

The CHAIRMAN. The chair recognizes the distinguished gentleman from Iowa, Mr. Nagle.

Mr. NAGLE. I'm kind of concerned. The staff has furnished me with a document dated May 4, 1977, a report to the Congress by the Comptroller General of the United States, and in 1977 there was a decision made to alter the testing procedures for this as opposed to past space endeavors. That report indicates to us on page 21, "NASA and its contractors have determined that a conventional test program for the space telescope would be extremely difficult and costly. It may not yield the desired data because of, one, the telescope's unique high precision requirements, and two, the effects of the earth's environment, such as vibration, atmosphere and gravity. Furthermore, it may be impossible to test this telescope to its full image quality in the very expensive test facility required to even approach this goal."

Then we were assured that "NASA presently plans therefore to test and calibrate the space telescope at the highest practical assembly level. The total system, therefore, will not be ground tested to make sure that it will perform as expected. Mathematical models and simulations will be used in lieu of much of the normal development testing. MSFC officials consider the performance risk associated with reduced testing to be acceptable. The space telescope will be thoroughly checked out after launch under space environment conditions which can never be perfectly simulated on the ground."

I'm just sitting here thinking that, you know, that's what we were told in 1977, that we were going to vary our normal testing patterns. That kind of became the godfather of this project as it moved through the 1981 completion, the 1983 delays, et cetera. The implications of that, however, for additional space projects that are on line, you know, is something that—I mean, are we doing our other projects on the same philosophy that we did the Hubble telescope? I mean, is that still the modus operandi within the agency?

Dr. ALLEN. Sir, I think Dr. Pellerin is present and perhaps could answer with regard to the Gamma Ray Observatory and the Advanced X-Ray Facility, which I'm not competent to do. But I believe it is not the general practice, and, in this particular case, what you have read was in fact the philosophy that was adopted in 1977 and carried all the way through.

I would guess at the present time that it led to overlooking what now we would know to be a very sensible thing to have done, and that is even though one could have found it difficult to make those very precise tests, there were less precise tests which could have been made that would have uncovered the error that we actually have. And I think adopting this philosophy caused people to overlook that point.

Mr. NAGLE. The second question I have is, whose decision was it to narrow your charter to the parameters that you've been charged with?

Dr. ALLEN. I would guess Dr. Fisk and Admiral Truly. Let me again point out that there is what is called a Hubble contingency plan—that is, a plan as to how to treat on-orbit failures—and we are following that plan. So we put this activity into place to do that particular part of the investigation. It is not the only investigation that should go forward. I think the ones that you're concerned about, the more general ones, should go forward as soon as we find the facts, as soon as we find out what happened.

Mr. NAGLE. The panel that was appointed, yourself, and I have the names here of the others, and to NASA's credit there are a couple of non-NASA people on the panel, but my question is the panel who was asked to do the investigation consulted about the parameters of the charter, or were you simply told what your charter would be?

Dr. ALLEN. We were told what the charter would be.

The CHAIRMAN. Will the gentleman yield?

Mr. NAGLE. Yes, of course. Absolutely.

The CHAIRMAN. It might be well that we would get a copy of the Hubble contingency plan as part of this hearing. If there's no objection, I would suggest that that plan be entered into the record at this point.

[The Hubble contingency plan follows:]

OFFICE OF SPACE SCIENCE AND APPL
HUBB

HUBBLE SPACE TELESCOPE CONTINGENCY PLAN

FEBRUARY 15,1990

Submitted:

Douglas R. Broome 1-12-90
Chief, Observatories Development Branch and
Manager, Hubble Space Telescope

Charles J. Pellerin Jr.
Director, Astrophysics Division

Approved:

L. A. Fisk
Associate Administrator for
Space Science and Applications

Concurrence:

George A. Rodney
Associate Administrator for
Safety, Reliability, Maintainability
and Quality Assurance

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

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1.0 INTRODUCTION

In accordance with NMI 8621.1E, Subject: Mishap Reporting and Investigation, the Associate Administrator for the Office of Space Science and Applications (AA/OSSA) is responsible for ensuring that plans exist to cope with accidents and mission failures within his jurisdiction, to investigate them, and to report the results thereof. Such plans and arrangements are required to be consistent with Chapter 2, NHB 1700.1 (V1-A), NASA Basic Safety Manual.

1.1 PURPOSE

The purpose of this plan is to define actions to satisfy the foregoing AA/OSSA responsibilities in the event of Hubble Space Telescope (HST) program-related accidents or mission failures, hereinafter referred to as program contingencies, as defined below.

1.2 SCOPE

This document establishes responsibilities for coping with and reporting HST program contingencies. It also establishes responsibilities for appointing contingency review boards, for outlining review board organizational requirements, and for conducting contingency investigations. Procedures for coping with Space Transportation System contingencies will be controlled by the appropriate Office of Space Flight documents.

1.3 APPLICABILITY

This plan applies to NASA Headquarters offices and Field Centers with HST program responsibilities.

1.4 DEFINITION

Program Contingency: For the purpose of this plan, a program contingency is defined as any HST program-related failure, accident, or incident (involving HST program-controlled flight or test hardware, support equipment, or facilities) that significantly delays or jeopardizes the HST program, or prevents accomplishment of a major (Level 1) objective.

1.5 DETERMINATION OF PROGRAM CONTINGENCY

The AA/OSSA will consult with the Associate Administrator for the Office of Safety, Reliability, Maintainability and Quality Assurance (AA/OSRM&QA), but will be the final authority in determining if an actual or suspected mission failure, accident or incident constitutes a HST program contingency. For this reason, despite uncertainty by reporting officials whether a contingency situation is in fact a HST program contingency (see preceding paragraph 1.4), the situation will be reported to the AA/OSSA for his decision.

1.6 EFFECTIVITY

This plan is effective immediately and will remain in effect through the completion of the HST mission.

1.7 CHANGES

The Director Astrophysics Division (Code EZ), NASA Headquarters, is responsible for maintenance of this document. Request for changes should be forwarded to NASA Headquarters, Code EZ, for review, coordination and action by appropriate organizations.

2.0 PROGRAM CONTINGENCY REACTION SEQUENCE

2.1 CENTER REACTION

In reaction to any suspected HST program contingency, the NASA Center at which the contingency occurs and/or the Center responsible for the activity during which the contingency occurs will implement their Center contingency reaction plan. The plan will include provisions for: (1) coping with the contingency, (2) immediate contact with the NASA HQ Safety Division to ensure proper notification, and (3) immediately notifying the HST Program Manager of the contingency (see Center responsibilities Paragraph 3.2). The notification should include a description of the contingency and its effect, its cause if known, events leading up to the contingency, what actions have been initiated or are planned, and recommendations for a course of action.

2.2 NOTIFICATION OF SENIOR NASA OFFICIALS

Immediately upon notification by the HST Program Manager, or his representative of an HST contingency, the AA/OSSA or his Deputy will determine if the situation does in fact constitute a HST program contingency. If so, he will immediately notify all personnel on the OSSA Contingency Notification List, including the Administrator, Deputy Administrator, OSSA officials, and the following other Headquarters offices external to OSSA:

A. NASA Safety Division: The NASA Safety Office will be notified of the contingency so that consultations with safety directors of other concerned government agencies can be conducted to resolve requirements for dual, overlapping or joint investigations (see Paragraphs 2.4 and 2.5, NHB 1700.1 (VI-A).

B. Office of Communications: The OSSA Public Affairs Officer (PAO) will be notified who will notify the Associate Administrator, Office of Communications. The OSSA PAO will implement their Public Affairs HST Contingency Plan and assure that all press releases are approved by the AA/OSSA or his Deputy prior to release.

C. The Associate Administrator for External Relations: The Associate Administrator for External Relations will notify the Congressional Relations Office and/or the International Relations Division of the contingency situation so that appropriate Congressional offices and/or international partners can be notified.

2.3 QUICK REACTION CONTINGENCY REVIEW CONFERENCE

At the time of notification of the AA/OSSA or his Deputy by the HST Program Manager (or his representative), the need for and the timing of a follow-on teleconference between NASA Headquarters and involved project officials to discuss details of the contingency will be established. The teleconference, if required, will be to determine the extent/impact of the contingency, whether the cause is known, the sequence of events leading up to the contingency, and corrective action taken or required. Because of the diverse situations that could constitute a program contingency, all appropriate participants for the quick-reaction review conference cannot be preselected. However, the nucleus of conferees will be the AA/OSSA, the Director, Astrophysics Division, the HST Program Manager, the HST Project Manager, and appropriate HST program /project personnel. Additional personnel who can provide first-hand details or advice on the situation may be invited to participate by any one of the designated conferees. Arrangements will be made by the HST Project Office to tie-in specified conference rooms at Headquarters, GSFC, KSC, MSFC, JSC, and contractor facilities as appropriate. If the contingency occurs during other than normal duty hours, the teleconference will be initiated at a time selected by the AA/OSSA.

2.4 DETERMINATION OF CONTINGENCY REVIEW LEVEL

Based on information obtained during the quick-reaction review conference, the AA/OSSA, in consultation with the Administrator, AA/OSRM&QA and others, as appropriate, will determine which, if any, of the following courses of action provided for in NMI 8621.1E, Subject: Mishap Reporting and Investigating, should be taken:

A. Option A - To implement this plan using an AA/OSSA appointed Board of Investigation, if the HST program contingency involves more than one Center or other organizations.

B. Option B - To implement this plan using a Field Center Director's appointed Board, if the HST program contingency involves only the functions and activities of that field installation, and if the damage/loss is less than that required for a Headquarters level board.

C. Option C - To implement this plan in support of an investigation or review to be directed by the Administrator or Deputy Administrator (see NMI 8621.1E , paragraph 8 for specific instructions).

D. Option D - To conduct an investigation outside the purview of this plan, if the contingency is determined not to be a HST program responsibility (e.g., STS failure), or one that does not require action by a formal review board (e.g., anomaly investigation).

2.5 CONTINGENCY REVIEW PLAN IMPLEMENTATION

If it is decided to implement this plan in support of an investigation (Options A, B, or C above), the AA/OSSA will advise the Director, Astrophysics Division, of the option selected and authorize him to execute the implementing actions listed in Paragraph 3.1.3B, below. Based on the option selected, the Administrator, the AA/OSSA, or a Center director will appoint a Board Chairman and act as final approving authority for Board membership as selected by the Chairman (see Sections 4.0 and 5.0 for Board Organization and Investigation Guidelines).

3.0 RESPONSIBILITIES

3.1 NASA HEADQUARTERS RESPONSIBILITIES

3.1.1 Associate Administrator for Science and Applications (AA/OSSA)

The AA/OSSA has primary responsibility for ensuring that plans exist to cope with HST program contingencies, to investigate them, to report the results to the Administrator, and to institute action to prevent recurrence of such contingencies. The AA/OSSA is also responsible for the following:

A. Determining if the contingency situation reported by the HST Program Manager or his designated representative does in fact constitute a HST program contingency (see Determination of program contingency, Paragraph 1.5).

B. Implementing the OSSA Contingency Notification List which provides for immediate notification of the Administrator and appropriate Headquarters officials of any HST program contingency (see Paragraph 2.2).

C. Conducting the quick-reaction contingency review conference (see Paragraph 2.3).

D. Determining the level of investigation required, in consultation with the Administrator, AA/OSRM&QA, and other appropriate officials (see Investigative Options, Paragraph 2,4).

E. Authorizing the Director, Astrophysics Division to initiate the implementing responsibilities stated in Paragraph 3.1.3B, if is decided to implement this plan in support of the investigation.

F. Approving all press releases prior to PAO release.

G. For an AA/OSSA-appointed Board of Investigation (Option A), the AA/OSSA will:

(1) Designate the Chairman.

(2) Serve as the final approving authority in consultation with the AA/OSRM&QA for Board membership as selected by the chairman and assure balance, qualifications, and third party nature of the Board.

(3) Convene the Board as early as possible consistent with any required support of ongoing flight operations.

(4) Assign responsibility for the contingency investigation to the appointed Board Chairman by formal message.

3.1.2 OSSA Division Directors

The Directors of OSSA Divisions are responsible for support of this plan by (1) participating in the quick-reaction contingency review conference, as required, and (2) maintaining Contingency Notification Lists for their divisions which will expedite contact with staff members during other than normal duty hours. The objective is to enable rapid contact with staff members whose specialties might be required to evaluate and advise on specific contingency situations. Additional responsibilities of the Director, Astrophysics Division are stated in the following paragraph.

3.1.3 DIRECTOR OF THE ASTROPHYSICS DIVISION

In addition to the general responsibilities stated in Paragraph 3.1.2, the Director, Astrophysics Division is responsible to the AA/OSSA for the detailed implementation of this plan.

A. Specific administrative responsibilities are to:

(1) Maintain this plan and the OSSA Contingency Notification List. (See appendix A).

(2) Ensure the preparation of compatible supporting plans by MSFC and GSFC.

(3) Assemble and maintain a Consolidated Working Group List. This list will contain two sections. Section I will be a listing of the single points of contact for each Center and Headquarters. These points of contact will be the HST Project Manager (Development) at the MSFC, the HST Project Manager (Operations) at the GSFC, and the HST Program Manager at

Headquarters. Section II will list the functions of all center-designated working groups and names of the working group acting chairmen.

B. Implementation responsibilities are to:

(1) Notify the Center Single Point of Contact when this plan and associated plans are to be implemented. Brief him on actions already taken and outline activities expected in the near future.

(2) Prepare and transmit an implementing message (see Appendix B).

(3) Assist the PAO in the preparation of press releases specifying the known facts and action being taken. Coordinate on press releases prior to approval by the AA/OSSA (see Paragraph 3.1.1).

(4) Provide a copy of the Consolidated Working Group List to the appointed Chairman of the Board of Investigation.

(5) Maintain a log of key event and actions taken.

3.2 NASA CENTER RESPONSIBILITIES

3.2.1 Center Directors

The Directors of MSFC, GSFC, JSC, and KSC are responsible for the preparation of Center plans that will provide for: (1) coping with contingencies, (2) immediate notification through program channels of the HST Program Manager of any suspected HST program contingency which occurs at their Center during activities for which their Centers are responsible, and (3) conducting or supporting HST program contingency investigations. The MSFC plan will cover contingencies during the development of the HST system up to the start of "Science Verification." The GSFC plan will provide for contingencies occurring during the operations phase of the program, for the period from the start of "Science Verification" through the end of the HST mission. Specific plan requirements are:

A. Contingency Reaction Plans: In reaction to HST program contingencies, Centers will be prepared, as appropriate, to:

(1) Take all possible action to prevent injury to personnel and damage to or loss of equipment and property.

(2) Secure the scene of the contingency, if applicable, against action that could impair investigation, e.g., protect areas and configuration integrity.

(3) Protect records, logs, data books, etc.

(4) Initiate a preliminary on-site investigation.

(5) Identify eye witnesses to the contingency event.

(6) Return relevant data to the appropriate Center for expedited data processing.

(7) Impound, in a bonded warehouse, any damaged hardware, equipment, debris, undamaged but related hardware, etc.

(8) Take appropriate actions to prevent recurrence.

(9) Support investigation of HST program contingencies under its own direction or under the direction of a lead Center, an OSSA Board of Investigation, or a board established by the Administrator.

B. Contingency Review Support Plans: In support of all foreseeable requirements which may be levied on them in the course of a HST program contingency investigation, Centers will prepare plans to ensure immediate response in the event this plan is implemented. Centers may issue a single plan to cover specific segments of the program and may draw on existing support plans for other programs for resources. Such plans will provide for the following minimum amount of support:

(1) Establish a Center Board of Investigation when delegated by NASA HQ.

(2) Participation in any contingency investigation directed by the AA/OSSA or higher authority and provide working group support as required (see organization and responsibilities of working groups, Paragraph 4.2).

(3) Establishment of working groups appropriate to the Center's areas of responsibility and maintenance of lists of working group members. The working groups list will name acting chairmen and specialists (including contractors) qualified to participate in contingency investigations (see Section 4.0). Each Center's Contingency Review Support Plan will designate the office responsible for maintaining the Center's lists.

(4) Informing OSSA Code EZ of the identification by name, with office and home telephone numbers of the "single point of contact" to be notified when this contingency plan is implemented. Also, provide to Code EZ a description of the functions and membership of any predesignated working group which might be activated for quick response to a HST program contingency.

(5) Use of action centers to relay necessary information and requests between Field Centers and Headquarters, if required. At the request of the Board Chairman, these action centers will be placed at his disposal and manned as required to support the Board during an investigation. Action centers will act as the points of contact for receipt and processing of directives from higher authority, receipt/release of information, requests for logistic support and requests for support from higher authority. The action centers will augment the functions of the Senior Administrative Officer [See paragraph 4.2H(3)] and will ensure that operational and administrative matters are channeled through one source.

(6) Use of existing facilities, organizations and procedures to the extent feasible for data handling analysis. Special Field Center data handling procedures are to be identified or referenced in the respective Center plans.

4.0 ORGANIZATION OF BOARD AND WORKING GROUPS

4.1 BOARD OF INVESTIGATIONS

When a Board of Investigation is activated and the Board Chairman has assumed his responsibilities, the duties of each board member will take precedence over all other duties. Board members should be designated from other Field Centers or government agencies as appropriate. Whenever personal injury is involved, at least one physician will be a board member. An appropriate safety official and a PAO will be used as advisors or consultants to the Board. At least one member of the Board will have completed the NASA accident investigation course or equivalent within the last two years. The proposed OSSA Board composition will be submitted by the Director, Astrophysics Division to the AA/OSSA for approval.

4.2 WORKING GROUPS

Working groups appropriate to the contingency situation will be activated by the Board Chairman. As a basis for the selection of groups for a specific contingency investigation, a Consolidated Working Group List of Center-established working groups and their acting chairmen will be provided to the Board Chairman by the Director, Astrophysics Division, OSSA. Any or all of the groups predesignated by the Centers may be activated. There is no limit to the number of specialty working groups which may be appointed.

The Board Chairman will appoint the Chairmen of the working groups activated. The Center-designated acting working group chairmen will act as working group chairmen until they are formally appointed by the Board. The working groups and the Board Chairman may rearrange the working group structures and define their roles as required. Maximum use should be made of both

government and contractor experts as consultants or advisors to the working groups and the Board.

The following is a list of working groups that will be considered for activation, depending upon the contingency involved:

A. Records and Witnesses Working Group

This is a group to obtain a review of contractor and NASA records pertinent to the contingency. It is to include records on receipt, inspection, configuration control, assembly, reliability, quality control, checkout, and modification. Records may be impounded if required. This group would also accumulate and review statements of witnesses as soon after the contingency as possible.

B. Launch, Landing, and Retrieval Working Group

This is a group to review the preparation for transportation, launch, landing, and ground service operations associated with the contingency. This includes landing and de-servicing at Trans-Atlantic Abort, backup, secondary and contingency landing sites as well as the primary landing site.

C. Spacecraft and Flight Vehicle Systems & Performance Working Group

This is a group to evaluate the HST and Space Shuttle systems instrumentation, pre-and post-launch data appropriate to those systems, and associated support.

D. Flight Operations and Ground Systems Working Group

This is a group to review Mission Control Center (MCC), Network Control Center (NCC), Space Telescope Operations Control Center (STOCC), and Space Telescope Science Institute (STScI) actions and the associated data which may have a bearing on the contingency. The areas of review may include flight plans, MCC, NCC,STOCC, and STScI configurations and procedures, flight control communications with the flight vehicle, and commands to the space vehicle.

E. Flight Crew Working Group

This is a group to analyze flight crew procedures, training, or other factors involving crew participation which may have a bearing on the contingency.

F. Procedures Review Working Group

This is a group to review the adequacy of all operating procedures and actions. Adequacy pertains to the adherence and compliance to the procedures, the effectiveness of the procedures, and the training certification processes.

G. Public Affairs Working Group

This is a group to coordinate the release of information in accordance with NASA NMIs and operational procedures as outlined in Center Support Plans. The group would develop and coordinate all public releases with the Board Chairman and also effect coordination through normal PAO channels.

H. Secretariat Working Group

This is a group (when warranted by the size of an investigation) to support the Board Recorder. This group would consist of a Recorder as its senior member, a Senior Administrative Officer and action center Duty Officers to provide administrative and logistic support to the Board to ensure an orderly progression of the Board's activities. Secretariat member functions are:

(1) Recorder

The Recorder will manage the secretariat function, and shall be responsible for providing all administrative and logistic support for the Board, for the preparation and dissemination of all administrative and operating procedures to be followed by Board members, and for compiling, safeguarding, publishing, and distributing reports of Board activities. The Recorder shall prepare and publish schedules of Board activities and shall arrange for other support such as access to controlled areas, special tests, photography, secretarial assistance, and special technical advisors.

(2) Action Center Duty Officers

When established, the action center will be staffed, as required, by Duty Officers who shall act as assistants to the Recorder in accomplishing his functions. All requests for administrative support shall be processed through the center. Duty Officers will maintain Board files, and will prepare and disseminate schedule and status information. A roster of all Board and working group members will be maintained. In addition, the center will serve as a focal point for all communication with the Board in such

matters as requests for information and support, receipt and processing of directives, and dissemination of status of the investigation.

(3) Senior Administrative Officer

The Senior Administrative Officer will arrange for clerical assistance, transportation, communications, and other facilities necessary to conduct an efficient and prompt investigation. The Senior Administrative Officer will also be responsible for the compilation, publication, and distribution of meeting minutes and/or required reports and other investigation administrative requirements. In the event coordination with an agency other than NASA is required, the Senior Administrative Officer will generally be responsible for setting-up and implementing the necessary administrative coordination procedures and will be responsible for processing and coordinating all necessary requests for funding and resources.

I. Staff Advisors Working Group

This is a group of advisors to support the Board in highly specialized areas. The Chairman, Board members, and Working Group may request assistance from this group as needed. As a minimum, the advisors should consist of people with expertise in the following areas.

(1) Legal Advisor

This is an advisor to the Board in legal matters associated with the contingency to include application of the Freedom of Information Act (Reference NMI 1382.2D)

(2) Safety Advisor

This is an advisor or consultant to the investigative Board to ensure the reporting requirements of Chapter 2 of NMI 1700.1 (V1-A), the NASA Basic Safety Manual are met.

(3) Security Advisor

This is an advisor to provide assistance and advice in interpretation and application of classification criteria, provide investigative liaison with federal and/or local investigative agencies as required, and provide non-technical investigative services.

(4) Public Affairs Advisor

This is an advisor to the Board to ensure timely release of information to the press and public.

5.0 INVESTIGATION GUIDELINES

5.1 GENERAL

The investigation will be conducted to determine the cause of the contingency and to recommend steps to prevent recurrence. The Board and each working group involved in the investigation will document their findings, determinations, conclusions, recommendations, and procedural methods used during the investigation. Guidelines for conducting a mishap investigation are provided in the NASA Basic Safety Manual NHB 1700.1 (V2).

5.2 SUPPORT FACILITIES

Centers should be prepared to support any investigation that may be required. Administrative facilities, rooms, secretarial support, sufficient communications, data access, and security systems should be pre-arranged, prior to the Board convening. Necessary resources to conduct the investigation will be made available to the Board.

5.3 SECURITY

Security, as it pertains to this plan, applies not only to classification of data, but also to restricting access to accident-sensitive areas to approved personnel. Security coordination with contract security services should be provided.

A. Personnel Access

Except for safety, health, and security purposes, the persons responsible for the security of the area involved will permit access only to those persons or groups designated in their Support Plans. After the persons normally responsible for security in the area involved verbally report the area safe for entry, the Center director or other person designated by the AA/OSSA will arrange for initial inspection of the site and prepare a preliminary report on the condition of the area to the AA/OSSA. As appropriate, key representatives of Headquarters, JSC, KSC, MSFC, and GSFC should be included for access during the initial inspection. The AA/OSSA has authority for access determination until responsibility for the investigation is turned over to the Board Chairman in accordance with Paragraph 3.1.1.

B. Integrity of Facilities, Equipment, Systems, and Impact Site Debris

Security of launch and landing facilities at KSC or alternate and contingency landing sites will be controlled by the KSC in conjunction with the Center security officer, as appropriate. Security of the areas at Cape Canaveral AFS, adjacent to the launch complex, and all other areas under his cognizance are the responsibility of the Commander, Eastern Space and Missile Center.

The overall security of the Edwards AFB (EAFB) area is the responsibility of the Commander, Air Force Flight Test Center, who draws upon Dryden Flight Research Facility (DFRF) support as required. Off-base security is the responsibility of DFRF with support from EAFB as required.

The GSFC Network Director is responsible for ensuring the security and integrity of all network resources such as the Network Control Center, Space Network, and the White Sands Ground Terminal.

The physical resources committed to support the HST at the time of the contingency will be preserved in their operational state and configuration until released by the AA/OSSA. Site debris will be moved only as authorized by the AA/OSSA, except when mandatory for rescue of personnel or fire fighting. The DOD forces and equipment which are available for location and removal of salvageable components are responsible to the DOD for command and control. These forces will move when directed by DOD. Arrangements will be made to store damaged hardware, equipment debris, etc., in bonded warehouses. Duties listed for the AA/OSSA in this paragraph will be assumed by the Board Chairman when investigative responsibility has been turned over to him in accordance with Paragraph 3.1.1. Exceptions to the above will be allowed when necessary to ensure crew safety.

5.4 DATA HANDLING

A. General

Data designated in the implementing message (see Appendix B), such as real-time recordings of telemetry, plotboard charts, trajectory data, tape recordings, weather reports, digital command system and tone command tapes, acquisition aid data, signal strength records, photographs, etc., will be reduced into legible format as soon as possible and distributed as required to support the investigation. When appointed, the Board Chairman may specify any special data requirements for use by the investigating authority. All other mission data may be processed in a normal manner.

B. Records

The HST Program and/or Project Manager may impound appropriate records and protect NASA records pertinent to the contingency which may include records of receipt, inspections, modifications, reliability and quality control, assembly and checkout, configuration control, and resolution of significant technical problems. A custodian within each working group will be designated for these records for use by the properly designated investigation board. Impoundment of information does not preclude its duplication for release after coordination by the AA/OSSA and the AA/Communications.

C. Security of Data

Data associated with the contingency will not be reclassified. To ensure all data are available to the Board, the distribution of these data will be restricted and accorded special handling procedures as specified in Center Contingency Support Plans. Except for direct support of continued flight operations and to the extent required by law, no information or data will be released to any person without a need-to-know, as designated by the AA/OSSA, until the Board Chairman for the investigation is appointed. To the extent provided by law, access to the processed and reduced data associated with the contingency investigation will be limited to personnel involved with the failure investigation until released by the Board Chairman.

5.5 STATEMENTS

A. Eyewitnesses

As appropriate, the senior manager at the contingency site, the Launch Director, Flight Director, HST Program Manager, HST Project Manager or Board Chairman will arrange for written statements as soon as practicable from any eye-witnesses or participants who may have knowledge or information considered pertinent to the contingency. DOD managers may be requested to arrange for similar statements, if appropriate. These statements will be held for delivery to the investigating board. Witnesses will be advised before they testify that:

(1) The sole purpose of the investigation is to determine all factors relating to the contingency and to preclude recurrence.

(2) It is not an objective of the investigation to obtain evidence for use in any personal disciplinary action against any individuals or to obtain evidence for such purposes, or to put any individual's employment in jeopardy because of the accident occurrence.

(3) The Board will endeavor to ensure that information pertinent to the mishap, if furnished under a pledge of confidentiality, will not be used or made available through disclosures for any other purpose to the extent permitted by law.

B. Public

Any public release of information relating to a contingency is the responsibility of the OSSA PAO. The AA/OSSA will provide guidance to the PAO, Launch Director, Flight Director, HST Program Manager, HST Project Manager, and other appropriate personnel and will approve all releases until a duly appointed Board assumes investigative responsibilities.

5.6 REPORTS

As soon as a contingency occurs, NASA management needs to know what occurred; what the extent of the damage was, how many (if any) personnel casualties or injuries resulted, and, if known, what the causes were. Telephone and Preliminary Reports, as outlined in Chapter 2 of the NASA Safety Manual, NHB 1700.1 (VI-A), meet these reporting requirements.

Progress, Final Progress, and Formal Investigative Reports, as defined in Chapter 3 of the NASA Safety Manual, will be prepared by the Board. The convening authority may also require the Board to prepare intermediate reports. The Board reports will be submitted to the convening authority and to other organizations as approved by the AA/OSSA.

The investigative groups will report their progress periodically and at prearranged intervals as established by the Board.

5.7 MINORITY REPORTS

If a Board member disagrees with the findings. conclusions or recommendations of a majority of the Board, his statement of non-concurrence will be appended to the report and become part of the report.

5.8 INVESTIGATION TERMINATION

The investigation will be officially terminated by the convening authority.

APPENDIX A

OSSA CONTINGENCY NOTIFICATION LIST

Name	Office Phone	Home Phone
Lennard A. Fisk AA/OSSA	202-453-1409	703-893-3689
Alphonso V. Diaz Dep AA/OSSA	202-453-1413	703-922-8252
Charles J. Pellerin, Jr. Dir. Astrophysics Div	202-453-1437	202-488-1423
Douglas R. Broome HST program Mgr	202-453-1450	703-280-1022
David J. Pine HST Dep. program Mgr.	202-453-1460	301-421-1030
Ralph C. Weeks Observatories Servicing program Manager.	202-453-2963	301-937-4819
George A. Rodney AA/SRM&QA	202-453-2406	301-460-5850
Kenneth S. Pedersen AA/External Relations	202-453-8310	301-987-9894
Charles R. Redman OSSA Public Affairs Officer	202-453-1549	202-363-3184
William Sheehan AA/Communications	202-453-1898	202-537-0941
Richard H. Truly Administrator	202-453-1010	
James R. Thompson, Jr. Deputy Administrator	202-453-1007	

APPENDIX B

NOTE: THIS SAMPLE MESSAGE IS TO BE PLACED ON A STANDARD FORM 14--TELEGRAPHIC MESSAGE FORM

TO:

GODDARD SPACE FLIGHT CENTER
ATTN: J.W. TOWNSEND JR., CODE 100
R. BAUMAN, CODE 300
P. BURR, CODE 400
J.V. MOORE, CODE 440

MARSHAL SPACE FLIGHT CENTER
ATTN: T.J. LEE CODE DA01
F.S. WOJTALIK, CODE TAO1

JOHNSON SPACE CENTER
ATTN: AARON COHEN, CODE AA

KENNEDY SPACE CENTER
ATTN: F. MCCARTNEY, CODE CD

ALL ADDRESSEES: PASS TO SAFETY OFFICE.

SUBJECT: IMPLEMENTATION OF HST PROGRAM

CONTINGENCY REVIEW PLAN, DATED NOVEMBER 30, 1989.

JSC, KSC, MSFC, AND GSFC [DELETE INAPPROPRIATE CENTERS]

ARE TO INITIATE THEIR RESPECTIVE CONTINGENCY SUPPORT

PLANS. THE FOLLOWING INSTRUCTIONS ARE TO BE FOLLOWED:

[IF FLIGHT IS NOT IN PROGRESS DELETE THE FOLLOWING SENTENCE]

THESE ACTIVITIES ARE NOT TO INTERFERE WITH ONGOING FLIGHT

OPERATIONS AND SUPPORT THEREOF.

1. THE AA/OSSA AND THE DIRECTOR OF PUBLIC AFFAIRS WILL PROVIDE GUIDANCE FOR RELEASE OF INFORMATION PERTAINING TO THE CONTINGENCY.

2. DATA ASSOCIATED WITH THE HST THAT WERE RECORDED BETWEEN _____GMT_____ DAY_____MONTH_____YEAR _____ AND _____GMT_____DAY_____ MONTH_____YEAR ARE TO BE IMPOUNDED. ACCESS TO THESE DATA WILL BE LIMITED TO PERSONNEL ASSOCIATED WITH THE CONTINGENCY INVESTIGATION WITHIN THE CONCEPT OF THE SUBJECT DOCUMENT AND TO MEMBERS OF THE PUBLIC IN ACCORDANCE WITH THE PROVISIONS OF NMI 1382.2D.

3. DATA MAY INCLUDE THE FOLLOWING TYPES:

A. ORIGINAL MAGNETIC TAPES RECORDED AT NETWORK STATIONS AND COPIES THEREOF.

B. UNCALIBRATED COMPUTER COMPATIBLE TAPES.

C. UNCORRECTED RADAR DATA MAG TAPES.

D. RADAR FUNCTION AND EVENT RECORDINGS.

E. UNANNOTATED TELEMETRY STRIP CHARTS.

F. SIGNAL STRENGTH RECORDINGS.

G. TELEMETRY SUMMARY TELETYPE MESSAGES.

H. OPERATIONS TELETYPE MESSAGES.

I. WSGT DATA TAPES.

J. TDRSS NETWORK DATA TAPES.

4. ONLY THE AA/OSSA (OR THE CHAIRMAN OF THE BOARD OF INVESTIGATION, WHEN APPOINTED), IN CONJUNCTION WITH THE APPROPRIATE SECURITY OFFICE, WILL ORIGINATE SUBSEQUENT MESSAGES RELEASING DATA ITEMS THAT ARE POSITIVELY IDENTIFIED AS NON-RELATED TO THE CONTINGENCY.

5. A SEPARATE MESSAGE FROM THE AA/OSSA, NASA HEADQUARTERS, WILL DESIGNATE THE STRUCTURE OF THE INVESTIGATION BOARD.

Mr. NAGLE. Which personnel at NASA made the decision as to the scope of your charter? Was it an agency decision? Were there minutes of the meeting? I'm really curious about the fact that you bring a bunch of experts in and you tell them this is what you're going to do, when their expertise may be indicative of something else.

The second thing I'm worried about, Dr. Allen, is that I think you're probably going to find what went wrong, you know, and at that point I'm afraid the inquiry may stop by saying that a contractor someplace or a subcontractor someplace down the line screwed up, and that's what caused it, and we'll never get back to the more fundamental concerns the committee should have about the process of testing, reliability verification, et cetera.

Dr. ALLEN. I believe, although I'm not the right one to do this, because I think that's Admiral Truly, I can assure you that will not be the case. Admiral Truly in his testimony before you today said a couple of times that he was looking to the investigation to provide him—and he used the word recommendations—on how to avoid this kind of thing in the future and on the testing procedures. That's outside of the charter itself, but——

Mr. NAGLE. But you're not authorized to do that.

Dr. ALLEN. Well, I'm still trying to distinguish, sir, between the fact that I have a narrow charter and have formed a Board consisting of narrow experts, but I believe that Admiral Truly expects me, as he would also expect Mr. Rodney, as a member of our Board and as the Associate Administrator of NASA in a broad area, he would expect us to provide him with broader recommendations and observations that will have more general utility to NASA's performance in the future.

But the Board, with these narrow optical experts on it, is aimed at just this narrow business of let's get the facts first.

The CHAIRMAN. Will the gentleman yield again?

Mr. NAGLE. Of course.

The CHAIRMAN. I think what we're basically saying, and that's what responsibility has been allocated to you, to look into what the facts that happened specifically in this narrow instance, whereas the members of the committee and others are coming back and saying, well, while we take the time to do that, that doesn't get to the root, basic problems as the committee ascertains them to be.

Dr. ALLEN. Yes, sir.

The CHAIRMAN. And it seems to me that it is in the interest of NASA to broaden your charter, so we're looking at the full overall view, particularly in the testing processes that would take place throughout NASA. Just to discover this one particular issue is not going to meet the charter that the committee has at this point.

I thank the gentleman.

Mr. NAGLE. I yield back the balance of my time, Mr. Chairman. Thank you.

The CHAIRMAN. The chair recognizes the distinguished gentleman from California, Mr. Rohrabacher.

Mr. ROHRABACHER. Thank you, Mr. Chairman.

It seems to me that what we're talking about here is a piece of equipment that did not meet specifications, and tests that should have been conducted in order to discover this fault that weren't

made. Being someone who has an organizational background, do you think that specific responsibility can be set for these two faults or for the fact that the piece of equipment didn't meet specifications and for the fact that tests weren't made that should have found out about the fault? Can responsibility be fixed?

Dr. ALLEN. It's hard for me to answer when we haven't gotten to what the mistake was, so I don't really know, but I guess I would have to say the answer is yes. That is, we should find the error, we should find the equipment that was made erroneously, whatever piece of equipment it was, and we should be able to identify where that error occurred and how it got through the process of verification and checking of the test equipment. So in that sense, we should be able to fix the responsibility.

Mr. ROHRABACHER. And you did mention the W word, as in who? Isn't it also your charter to determine who was responsible?

Dr. ALLEN. Yes, sir.

Mr. ROHRABACHER. Well, as an organization man, as someone who has come up and organized systems for our country's defense and for other purposes, do you think that the mistakes that were made and the cost this has been to the taxpayers, is this one of those mistakes where heads should roll?

Dr. ALLEN. I wish I knew how to answer that in advance, and I don't. I guess I would have a suspicion that it won't be that clean; that is, that we will find that there was an error made, that there were checks that could have been done to find the error that were not done, that there was a rationale which seemed good at the time for going the way they did that in retrospect was erroneous, and at that point you are led to a conclusion, I am guessing, of course, because we haven't done it, but you're led to the conclusion that the right thing is to be sure that doesn't happen again by taking different approaches in the future and that you will not conclude that heads will roll.

But on the other hand, as I said earlier, it's inconceivable that the outcome of the investigation will not be extraordinarily embarrassing; that is, there clearly has been an error made, the error should not have been made, the error, if made, should have been caught, and those things didn't happen, so that is going to be a very awkward thing to adequately rationalize.

Mr. ROHRABACHER. Well, this mistake is going to cost the taxpayers I would say at least hundreds of millions of dollars, and I think there's a cynicism throughout our country about the way we operate here in Washington. Everybody thinks that we're all part of some country club here, and when somebody makes a mistake that costs people hundreds of millions of dollars on the outside that we just sort of shrug our shoulders and say, "Well, you know, you can play through to the next hole, Fred," and it seems to me—well, let me give you a specific question.

If a company did not produce a piece of equipment to meet specifications, shouldn't they be the one that pays for that mistake?

Dr. ALLEN. In the commercial world, that would certainly be the case. In the Government world, in R&D contracts, the contracts are generally not written that way.

Mr. ROHRABACHER. If someone was supposed to determine whether or not a test was made which would have found out about this,

which would have actually discovered this, and it was his decision whether or not to proceed with the test, and, as you say, some of these tests aren't as expensive as people would believe or have us believe, should that person lose his job for making that wrong decision?

Dr. ALLEN. I wish I could—the line of questioning you have, of course, is the one we would all like to think would be the case, and it's very tempting to agree with you and say, "Yes, I'll identify the person who on some particular day said forget that test, we don't have to do it."

I have a feeling, and I'll, of course, find this out when I investigate, that it won't be that clean; that is that there were review groups set up to review these, there were collective decisions made that the Government, in terms of the project office, concurred with these decisions, that there was a whole trend of philosophy of how to do the testing which was consistent and rational at the time and turned out to be wrong.

And when you go back and try to say, "But did Joe make a bad decision?," the answer will be, "Well, yes, it was Joe, but it was the project office and it was the review group that reviewed all that, and it turned out to be wrong." And I hope I can find both a smoking gun and a fingerprint on the trigger, but I'm afraid it will be a little bit more complex than that.

Mr. ROHRABACHER. Well, Dr. Allen, just in closing, our shuttle fleet is grounded, we've gone through catastrophes, we have cost overruns from NASA every time we turn around, and we're talking about billions of dollars at the same time people in this town are talking about freezing Social Security payments. This is a very frustrating experience. I'm a freshman here, this is my first term in Congress——

The CHAIRMAN. Wait until you've been here for 10 years. [Laughter.]

Mr. ROHRABACHER. It just seems to me that there's a lack of responsibility with the people within the system making decisions, and I would hope that at least that can be corrected in the future. Thank you very much.

The CHAIRMAN. Thank you.

I'd like to at this point—I know there are a couple other questions, and, of course, we've got to press our time—I'd like to ask Dr. Fisk to come back up, will you, and sit with Dr. Allen for a moment, and then I think you were the proper one to ask that question to in the first place.

What we'd like to get on the record is who determined Dr. Allen's charter, whether NASA expects management recommendations from Dr. Allen, and what NASA will do with Dr. Allen's findings. Will there be a new panel? And I'll tell you where that's leading from.

There have been a lot of general questions that have been asked here that I think are important. You know, if we can't find the chain of events and so forth, I don't know how one could talk about liability, you know, revisiting contracts, opening up contracts and repayment to the Government. I don't want the people to go away thinking that's an illusion. So if we're only going to be looking into the technical facts here, I don't know where that goes in the sense

of what the committee is concerned with. Would the gentleman respond to that, please?

Dr. FISK. Yes, thank you. I appreciate the opportunity to clarify this. Let me assure you, first of all, that NASA will drive this problem to the ground. We will find out not only what happened, we will find out when it happened in the testing and what the implications of that are and what management changes should be made, what changes in testing, whatever are the implications from this.

First of all, I'm the person who is responsible for the charter. You wanted to know——

The CHAIRMAN. That's why we called you back.

Dr. FISK. You'll find my signature on the letter, and I'm afraid I'm a sequential thinker here. I mean, Hubble, of course, had a variety of management issues associated with it which have been reviewed, you know, extensively over the years by this committee, by other committees, by NASA, what have you. Rather than set out a broad charter to revisit all the issues associated with the Hubble management, many of which are probably irrelevant for this particular problem, we chose to work this thing in the following order: figure out what happened, figure out why, figure out why it was missed, take that information, determine from that what was the cause of that problem. Was it a management issue?

I mean, you can imagine a variety of causes, for example, that you might want to pursue, depending on what the outcome is. Someone made a technical error. They put something in backwards, let's say. Then you say, well, that's a quality assurance issue. It doesn't have to do with associate contractors and which center was in charge and so forth; that was a quality assurance issue, if that was the case. And then you trace down the quality assurance line to find out what it was, what was the implication for quality assurance, did we do the same things then as we do now, et cetera.

Suppose it was a set of instructions that were somehow confused as a result of, you know, from the project to the contractor. Well, that may be a center management issue. First of all, my logic is to figure out what happened and then from that pursue whatever is appropriate to trace down the implications of that for the Hubble structure at the time and what we do today.

But please rest assured that we will not let this rest until we know all of the implications that come from this problem.

The CHAIRMAN. Are there any further questions?

The gentleman from Pennsylvania?

Mr. WALGREN. Yes, Mr. Chairman, if I might.

Dr. Fisk, you indicate that, well, clearly, you have to find out the exact facts that happened here, but, ultimately, isn't this a testing issue?

Dr. FISK. That is certainly going to be——

Mr. WALGREN. It's not so much a question of whether somebody put something in backwards inadvertently, we all know that happens in human affairs, but the question is why weren't the proper tests run?

Dr. FISK. Absolutely.

Mr. WALGREN. Then let me ask Dr. Allen, you say in your testimony that there has been a good deal of discussion about the need

for an independent characterization and test facility, but then you go on to say this needs some clarification. "The project and contractor personnel decided against performing such tests, because they would have had to have been extremely precise, which translates into expensive"—now, those are your words—"in order to measure the accuracy of the primary mirror."

Now, Dr. Fisk said earlier that the question of tests was not a question of cost but was a technical question and that the tests were turned away from on the basis of their technical considerations. How do you square your testimony in which you say that the project and contractor personnel decided against performing such tests on the basis of cost, when Dr. Fisk says that cost was not a question but rather it was a technical decision?

Dr. ALLEN. I believe it was primarily a technical decision, and I think in many ways the philosophy which led to that kind of a decision is best explained by the paper which Mr. Nagle read, which was the 1977 one that discussed the reasons for going about the test philosophy.

There was a rationale developed which was consistent which said our efforts are best put by measuring the components very precisely and then being sure that we assemble them correctly and that to do the all-up system test correctly would be very difficult, would be hazardous in the sense of contaminating the mirror, and would be very expensive. But I think it is correct to say that it was not a limitation on funds that drove the decision.

Dr. FISK. If I can add one grave elaboration to this that didn't come out in the earlier hearings and might be worth noting, one of the reasons you might have pursued an end-to-end test like this is to make sure that the mirrors were properly aligned together, you know, that they fit in the optical assembly in the proper way. And when it was recognized that you were not going to do an end-to-end test like this, the system was designed so that the mirrors could be moved relative to each other so that when you got on orbit you could make this alignment adjustment and not have to do it as part of an end-to-end test. You say, "I couldn't simulate on the ground adequately the effects of lack of gravity," and so I build into the system the ability to adjust the mirrors in orbit, and that works fine. We make those adjustments.

Mr. WALGREN. Mr. Chairman, if I might try to make one important point, to me anyway, and that is that I want to be sure that no one is confused that although we agree you could not do the end-to-end test that somebody left out some very simple tests that could have been done, and we have NASA repeatedly expressing the fact that there's this contamination and there's difficulty in doing the end-to-end test and reason not to do it; that is not reason not to do the simple characterization tests that Dr. Allen goes on to say in his testimony, "On the other hand, using relatively simple and inexpensive characterization techniques, the aberration that apparently actually exists would have been detected."

So I hear NASA saying don't ask us to do these tests because they're so expensive, and yet you're talking about a different level of testing than Dr. Allen indicates would have found this flaw, and our question is, why didn't you do those simple tests, not why didn't you do these very expensive tests?

Dr. FISK. Sir, that's a very appropriate question, and I don't disagree with it in any way. And we're asking the same questions.

The CHAIRMAN. The gentleman from Pennsylvania, Mr. Walker?

Mr. WALKER. Thank you, Mr. Chairman.

I want to get back here for a moment, if I could, to, Dr. Fisk, your response with regard to Dr. Allen's charter. Now, if I understood you correctly, the reason for the narrowness of the charter is because sequentially you want to make certain that you get the first questions answered first, and that's certainly understandable. What I didn't hear, though, was the answer to the second part of the chairman's question, and that was, "are you expecting as a part of that first sequence to get some management recommendations from Dr. Allen?"

Dr. FISK. I expect to get at least by inference management recommendations in the sense that what will come from this is when you know the cause; therefore, you know the parts of the management that are responsible for that cause.

Mr. WALKER. Sure.

Dr. FISK. Now, let's just carry this to its logical extension here. If you know that, then you can say, now, how best do I evaluate the causes that occurred to this thing? It may well be that I see within Dr. Allen's panel the ability to make those recommendations.

The CHAIRMAN. Will the gentleman yield? What is coming very clearly now, and sometimes it takes hours of reflection to get to the point, what is very clear now is that NASA's interpretation of the situation they're faced with is a technical problem, and, if the gentleman would yield, that's what's coming out because the charter doesn't specifically say beyond that what we do. So that we look at this as a much broader problem or potentially so.

Mr. WALKER. Yes, and the point I want to make is—well, go ahead and finish.

Dr. FISK. Please let me finish. We look at it as a broader issue as well, but I'm taking this one step at a time. If we stopped at the end of Dr. Allen's panel, then we've not done our job, because we've dealt with it only as a technical issue. We won't stop at that point. We will stop and say now that I know what happened, let's examine the causes of it, management causes not technical causes, and what are there implications on what we're doing today.

Mr. WALKER. Okay, my question goes to precisely that point now. Is it your intention to go to another outside group or to extend the charter of Dr. Allen's group at that point? Because when we got to the question of the Challenger, I think it was extremely important to the credibility of what we finally ended up with to have an outside panel of distinguished experts who finally came up with recommendations for you to proceed onward.

Now, I think that's going to be extremely important in this case, too, that we not allow the process to simply be Dr. Allen's report and that in attempts to correct from within that we also move toward the type of panel that can lend credibility to the final solution.

Dr. FISK. I quite agree. What I don't know today is, of course, how to constitute it, because I don't know what problem I'm trying to solve.

Mr. WALKER. Precisely. Okay, that's fine, but it is your intention to move toward another kind of outside group that will help you make some of these fundamental decisions that——

The CHAIRMAN. Well, if the gentleman will yield on that, where the chairman is coming from at this point, I think, number one, how long is that going to take? And I know you can't nail that down. The American people are not going to wait for six or eight or nine months for a scholarly decision of what may have happened four years ago. We're going to be taking the NASA budget to the floor, we're going to be in conference with the Senate on the appropriations end of it and so forth. Should this committee start to think two things that I just got done saying to the staff a few years ago—well, let's get a letter off to Admiral Truly and tell him we want that charter expanded, or two, should we go in and bring GAO——

If we were distressed with Perkin-Elmer doing the mirror, doing the test, nobody's checking on it or even getting a chance to get an evaluation. Is NASA capable of evaluating itself on this issue alone? That's the fundamental question. For NASA's good, do we need an independent body saying, "Well, here's what we've gathered, here's what Congress thinks, this is exactly what happened technically," but we're coming back and saying, "Are you capable of evaluating it yourselves?" Isn't that what we're saying about Perkin-Elmer? You made the mirror, you did the test, you installed it, we didn't have to do other tests, they only were assiduously doing their own thing.

Now, here, are we saying back to NASA that NASA is coming back, and that's the difference between this hearing and the point that the gentleman from Pennsylvania is making on the shuttle situation. We had an absolute independent group.

In the meantime, we'll leave you to ponder that while we go cast our ballot in the interest of the country, and we'll return as soon as we can.

[Recess.]

Mr. NAGLE [assuming the chair]. Our next panel is Dr. John Bahcall, Dr. Bless, Dr. Stockman, and Dr. Oertel. I hope I pronounced those correctly.

Dr. Bahcall, do you want to start us off?

Dr. BAHCALL. Sure. I want to point out, Mr. Roe, that we have been trying to conduct our own test here——

Mr. NAGLE. You have made a serious error to begin with, Dr. Bahcall. I am much better looking than Mr. Roe.

Dr. BAHCALL. Oh, you're Mr. Nagle. That's right.

Mr. NAGLE. I'm Mr. Nagle.

Dr. BAHCALL. You're Prosecutor Nagle, if I remember correctly.

Mr. NAGLE. Yes. The old man over here to my right is the chairman, who will now sit in his chair.

The CHAIRMAN [resuming the chair]. You may proceed.

STATEMENT OF DR. JOHN N. BAHCALL, PROFESSOR OF ASTROPHYSICS, INSTITUTE FOR ADVANCED STUDY, PRINCETON, NJ

Dr. BAHCALL. Sir, I wanted to say that I am speaking today as President of the American Astronomical Society and as a senior

member of the Science Working Group that has been responsible for giving science guidance on the space telescope since 1973. I have been here many times in the past to promise you beautiful pictures and great discoveries, and I come today to share with you the heartbreak that we all have in not being able to provide those discoveries to you as soon as possible.

But I noticed a question earlier today from I believe it was Congressman Buechner asking if there were warranties in this area, and although you haven't received a formal warranty, I can offer you a warranty on behalf of all of the scientists and all of the engineers in the program that this problem will be fixed, and we will do what we have promised to do if that can be done by human beings working 12 or 14 hours a day, because we've all been doing so.

I have every reason to believe that the problems will be fixed. Unfortunately, the problem that we now have is pretty much like if the Hubble telescope could feel, I'm sure the telescope would feel like an All-Star batter who shows up for the first time at a World Series game with the eyes of the world on him and with the full expectations that that batter will perform extraordinarily well and suddenly finds out that he's left his contact lenses at home. I think we will get back to what we expected to get before, but we are not there now.

Now, what I thought I would do, Congressman Roe addressed the issue earlier, I thought that what I could best do for you is let you know some of the things that we expect to be able to do and some of the things that we cannot do with the present configuration so that you will appreciate what this is all about to science and what we're losing and what we will in fact have.

A problem program which we have come many times to the Congress to discuss is the program determining the size and the age of the universe. I think we all have an interest in knowing how big the universe is and how old it is. Unfortunately, that's a problem we can't address with the telescope in its present state, because that involves ability to discriminate faint stars in the presence of other faint stars and determine their brightnesses accurately. The telescope can't do that. That's one of the two principal goals of the telescope that we have been talking about for many years.

If we succeed in getting the slide projector to work, I will show you a computer simulation of a program which broke my heart, because I can remember in 1975 first coming to the Congress and describing to you in the Congress the nature of the problem with quasars, which I think some of you at least know are the most distant and the brightest objects in the universe. They shine as brightly as a billion stars, but they have a volume no bigger than our own solar system.

We don't know what makes them shine, we know, we think, what makes the stars shine, and the space telescope was designed to answer that question in part. I have as part of my personal observational program to answer that question, and I wanted very much to bring you pictures which would answer that question. I have computer simulations of what the answer might be, but I don't know how valid they are or whether they bear any resemblance to the truth.

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In fact, for quasars, we don't know if a quasar phenomenon is something that occurs in the death rows of an old galaxy or in the birth pangs of a young galaxy, and the space telescope was designed to be able to enable us to take a picture of the faint galaxies that are around the bright stellar images of the quasar.

With the telescope in its present configuration, we will not be able to do that, although we may be able to see that on the slide projector soon. I hope to be able to show you that in a little bit.

We've heard mostly bad news this morning; there is good news, and I want to not shortchange that. The ability of the telescope to look in different colors, not just in the ultraviolet but in all different colors, is not compromised, the spectrographs, the faint object spectrograph and the high resolution spectrograph, can do the great majority of their programs.

There is some bad news with that, and I will show you what the bad news is with an end-to-end test which I can control myself. I hope it works. But the bad news about that is that with the image quality the way it is, with the optics the way it is, the image is so diffused that we can't get a lot of the light in the small holes that we need to in order to break the light up into the colors that we want. So that will mean it will take longer to do things than it would otherwise have done.

I told you before that there was one key program of the space telescope, which is to measure the size of the universe and its age. There's a second key project of the space telescope awarded also a lot of observing time, and that is to determine what there is between us and the most distant objects in the universe, and, again, the analogy is a flashlight, if you're in a—you can't see it now, but we'll turn off the lights in a minute—if you're in a forest at night, and you want to know what's between you and the animals that are out there, you shine your flashlight, and you can illumine the things between you and us, and we have with the telescope the ability to illumine the medium, the material, the universe between us and the most distant edges of the universe, and that ability we still have, and we will find out what's out there.

For this key project, it will take us about two and a half times as long to do as we had expected to do. So that's the bad news. The good news is that we can in fact answer the question of what is out there.

Now, in fact, I wanted to show you this. Some of you may be wondering why I brought a football to the hearings today. In 1969, Lyman Spitzer and I—Lyman Spitzer is the person who first proposed this telescope, shortly after the Second World War—proposed a theory that galaxies which look something like this football are really enormously bigger, that they have halos which are about 10 times bigger in any direction, so 100 times bigger in radius, and so what we're going to still be able to do with this telescope is test that idea by looking in the ultraviolet for the absorption.

When you shine the bright quasar light, if you can just envision that, you shine the bright quasar light past galaxies not at the place where you can see the material but where there is expected to be, according to this theory, a lot of gas out there, and that's an experiment which will tell us how big galaxies are and what

they're made of, and the telescope can fully do that experiment. It's one of the key elements for which the telescope was designed.

We will still be able to look in some ways for the possibility of planets outside our own solar system, but in terms of imaging, that will not be possible. I'm going to ask to see if—we're not quite at the point of looking at these computer simulations yet, so——

Could we, Mr. Chairman, Mr. Roe, turn off the lights, and I hope to——

The CHAIRMAN. The bell is going to ring in a couple of minutes, and we've got to go back and vote, but let's go with it.

Dr. BAHCALL. All right. This is a simulation on your left of what you can do from the ground when you look at a bright quasar, and you can see that there's a central image there, a sort of stellar image, and then a watchband around it, this watchband area here, and that's just an overflow of light, but we're really looking at the faint galaxy. See this part here? That's what we were going to look for, is those spiral arms that would indicate what a faint galaxy is around the quasar. That's a simulation of a very famous quasar with our own galaxy underneath it. A computer simulation, unfortunately, not what the telescope can do.

That on the left is the very best we can do from the ground now. This is what the design of the space telescope would do if our own galaxy was underneath that very bright quasar. And if we can see the next image, this is what we can do now, and you see we just can't do it.

If you can show me the next image, this is what we had hoped to do for the cores of globular clusters, the faintest and most beautiful of all the collections of stars in our galaxies. If we have the next image, this is the image of what we can do now. It's still a lot better from ground, it's a major improvement, but you can see that the image is ugly, and that's about what we can do for now.

If we leave the lights off, I will try to show you—I have my own demonstration—this is kind of what our problem is now, and this is that image, and this is what we were hoping on, so the fact that we take longer to do our experiments is just that the image is so big so that any hole of a given size that we have to put the light in, we're going to lose a lot of the light. It's because of the focus that we're having so much of a problem.

I'd like to close by telling you that—if we could have the lights—I'm convinced that the telescope and the instruments will function after correction as designed, that the HST will provide partial answers to the fundamental questions which we've been promising the Congress that we would answer with this expensive device for 17 years, at least.

Other questions, such as the size and the age of the universe, will require years before we can attack them with the telescope, but on the short time scale of a year, we will have answers to fundamental questions and new questions to bring to the Congress, and I look forward very much to bringing those to you.

However, I think that's not what the space telescope is about. I think the space telescope, as marvelous an achievement as it is, and by the way, I've had a lot of honors in my career over the years as a scientist, my colleagues know that, recognized by my colleagues in many different ways, and there is nothing in my person-

al or professional life of which I am prouder than it is to be a member of the Hubble Space Telescope Team.

Congressman Roe, other members, this is a marvelous technical achievement. There's been one very stupid error, but I'm very proud to have been part of this team together with 10,000 other people that got us here in a place which no other nation could have done.

Now, in my personal view, we're going to make discoveries about things that we can't even ask about now, and I expect us to come back and tell you about those, and I hope you will invite us to share with you the discoveries that we will make. I expect us to find things that we haven't anticipated, and in fact I think a failure to discover unimagined objects and to answer unanswered questions——

The CHAIRMAN. We're going to have to stop you, because we're on the second call, and you wouldn't want us to miss this vote.

Dr. BAHCALL. Okay.

[The prepared statement of Dr. Bahcall follows:]

STATEMENT TO THE

SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

OF THE

U. S. HOUSE OF REPRESENTATIVES

Washington, D. C.

July 13, 1990

Science with the Hubble Space Telescope

by

John N. Bahcall

The Institute for Advanced Study, Princeton, NJ 08540

INTRODUCTION

Thank you for the opportunity for sharing with you the heartbreaking disappointment that all of us in the Hubble Space Telescope (HST) program feel in the delay in achieving some of our most important scientific objectives. I want to assure you that every person in the program is dedicated to making certain that three or five years from now you do see the beautiful and important pictures of the universe we have been promising you and the American people for almost two decades. I speak to you today as President of the American Astronomical Society, as a member of the scientific working group of the HST since its inception in 1973, and as the principal investigator on one of the Key Projects of the HST scientific program, as well as a principal investigator on several smaller HST projects.

Let me begin by reminding you of the advantages of the Hubble Space Telescope over groundbased telescopes.

The principal advantages are two-fold: 1) Sharper images and 2) A wider range of colors. The first advantage, clarity of vision, is severely compromised by the wrong prescription to which the mirror was ground. The cameras aboard HST, while working perfectly, cannot be used now to see with the precision that was planned. Corrective action is required. The second advantage, the wider range of colors that can be viewed, is not affected.

The HST is in orbit where the stars no longer twinkle, beyond the earth's atmosphere. This will make possible in a few years images of astronomical objects with unprecedented resolution. The HST will have a sharpness of vision that is about ten times better than is usually obtained with the best ground based telescopes. HST will ultimately have a resolution sufficient to read the writing on a dime at the distance of three miles, or more technically, about one-twentieth of an arcsecond. This factor of ten improvement over the resolution typically available at the best groundbased sites is crucial for many of the science projects that have been prepared for the observatory.

Unfortunately, the HST Observatory, if it had feelings, would be feeling now pretty much like an All Star batter at home plate for the first time in a World Series with the eyes of the world on him, a batter who suddenly realizes he left his contact lenses at home.

Fortunately, the observatory will be able to look in colors that cannot penetrate the earth's atmosphere. To get a feeling for how much potentially this could increase our knowledge, think about what an incomplete picture you would have of this room if the only color you

could see was green.

Outline of Talk

I will illustrate for you the impact on the science programs by considering a few important examples.

How do we determine the size of the Universe?

To determine the size of the Universe, we need to measure distances to galaxies that are running away from us. The fundamental law that is used here states that objects in the universe are expanding away from each other with a velocity that is proportional to their distance from each other, their separation. To visualize this situation, imagine that the galaxies are spots on the two-dimensional surface of an expanding balloon. Then each galaxy moves away from all the others with a velocity that is proportional to the distance between the galaxies. More distant galaxies separately more rapidly.

With ground based observations, we can measure the speeds with which galaxies are moving away from us. We need to find some way of measuring their distances in order to find the scale of the universe.

Stars that pulsate with a definite period, typically between two to sixty days, have fixed intrinsic brightnesses. Their period determines their wattage, a result established by ground-based observations. Thus if we measure the periods of distant stars we know how intrinsically bright they are, how much light they are putting out. If we can measure also their apparent brightnesses, how much less bright they appear than similar stars seen in our own Galaxy, we will know how far away are the distant galaxies.

The high resolution of the HST will be used to identify individual pulsating stars among the tens of billions of other stars in the same direction. For distant galaxies, this can only be done from space.

The velocity with which a distant galaxy recedes from us is proportional to its distance from us. The proportionality constant, known as Hubble's constant, measures the expansion rate of the universe. In the expanding balloon analogy, the proportionality constant depends upon the amount of air you blow into the balloon every second. The inverse of this constant is a measure of the age of the universe; the inverse of Hubble's constant describes how long the universe must have been expanding in order for the galaxies to reach their current separations. This age is roughly ten to twenty billion years, but we hope to determine the value more accurately with HST.

These important objectives of determining the size of the universe and its age can only be addressed properly by the HST telescope once the corrective optics are supplied to the new cameras. The reason is that one must measure accurately the brightness of individual pulsing stars in the presence of many other stars in distant galaxies. With the equivalent of corrective contact lenses, the telescope cannot see clearly enough to decide how much light comes from the many stars that appear closely packed together.

What are quasars?

Quasars are the most distant and luminous objects known in the Universe. They can be observed all the way back to the early childhood of the Universe (more than 95 percent of the way back to the beginning of cosmic time), corresponding to something like a four year

old for an average human life span. The total light emitted by these enigmatic objects is equivalent to the light from a thousand billion stars. In pictures taken with groundbased telescopes, quasars nevertheless look like single point-like stars, with some barely visible evidence of indistinct smudges surrounding the nearest quasars.

Most astronomers believe that quasars are something that happens to a galaxy, either the death throes of an old galaxy or the birth pangs of a young galaxy. Or, perhaps, the violent collision of two galaxies.

With groundbased telescopes, we cannot see the galaxies that we believe are associated with quasars because light from the star-like central quasar image is smeared out by the earth's atmosphere so that the faint diffuse light from the associated galaxy is hidden. With HST, we hope to see the light from the mother galaxies of the quasars and to find out if quasars are galaxies in the process of being born, or old galaxies in the final stages of some terminal disease. We hope that knowing where quasars form will help us figure out how they shine.

This program of unmasking the quasars cannot be done until the cameras get contact lenses. Figure 1 compares the image that will be obtained with the telescope when the cameras are corrected with the image that can be obtained from the ground. You can see from this figure that we should ultimately be able to tell in what kind of galaxy, if any, quasars live. Figure 2 shows what we can expect to see with the current optics. I have two approved HST research programs that involve taking pictures of about 20 quasars. I will defer these programs until the cameras are repaired.

Are there imaging programs that can be done without contact lenses?

The HST mirror results, without any corrections, in a sharp focusing of part of the light that is better than can be achieved from the ground. For a small fraction of the programs that were planned with HST, the principal scientific aims can be achieved without serious compromise by concentrating on the small part of the light that is tightly focused. Figures 3-5 illustrate the advantages and limitations of the images that can be taken without correction compared with what is available from the ground and with what will be possible when the new cameras are installed.

Mostly good news.

The ability of the telescope to look in different colors, especially in the ultraviolet, is not compromised. The spectrographs can be used for the great majority of the original programs in which high spatial resolution was not also combined with color resolution.

Unfortunately, there is a loss of efficiency. In order to obtain the color resolution that is required for most of the programs the light from the stars must be directed through a small hole. Because the light is not well focused, much of it cannot be used. Different programs will be affected in different ways by this problem. For the longest exposures, which involve some of the most interesting science, the required extra spacecraft time may be four times longer. For shorter exposures on brighter objects, the net increase in spacecraft time may only be an additional 10 percent or so.

Let me give you an example of the kind of science that can be done with the spectrographs on the HST.

What is there between us and the most distant objects in the Universe?

With the HST, we will use quasars-the most distant and brightest objects we know about in the universe-to illumine the path that light takes between us and these distant sources of light. We will use quasars as bright flashlights to reveal what there is between us and them, much as we use flashlights on earth to show what unknown things face us in the dark.

An example of the kind of question that will be answered by these observations is: How big are galaxies?

In 1969, Lyman Spitzer and I proposed a theory in which typical galaxies have huge halos of gas surrounding the bright regions in which stars are visible. According to this idea, the radius of a typical galaxy in gas is on the order of ten times larger than it appears on groundbased pictures of the light emitting regions of the galaxy. The proposed halos are dark and do not emit starlight. This suggestion will be tested definitely with HST by observing light from distant quasars that passes near, in projection, the images of galaxies that are along the line of sight between us and the quasars. If the galaxies are as big in gas as we suggested, then they will block off light from the quasars even when the galactic image, taken in starlight, appears to be relatively far from the line of sight to the quasar. This project can only be done from space because the strong absorption caused by relatively nearby galaxy halos (or by intergalactic clouds) are in the ultraviolet region of the spectrum, which does not penetrate the earth's atmosphere.

All of us want to know if there are intelligent beings on planets around other stellar systems.

What can the HST tell us about the existence of planets around other stars than our sun?

Scientists using the HST will search for planets around nearby stars in two different ways. Astronomers will attempt to *image* the planets around other stars using both cameras on the HST. It may be much easier to detect the material out of which planets formed, the rotating disks out of which planets like our own (the earth) are believed to have developed. There are many observations planned of stars in the Taurus constellation which may reveal that a number of these young stars have disks which will ultimately form planets.

Other astronomers will try to detect planets using the indirect wobbling motion of the stars caused by the gravitational pull of their hypothetical planets. These observations will be very difficult, but are obviously of great importance and of public interest.

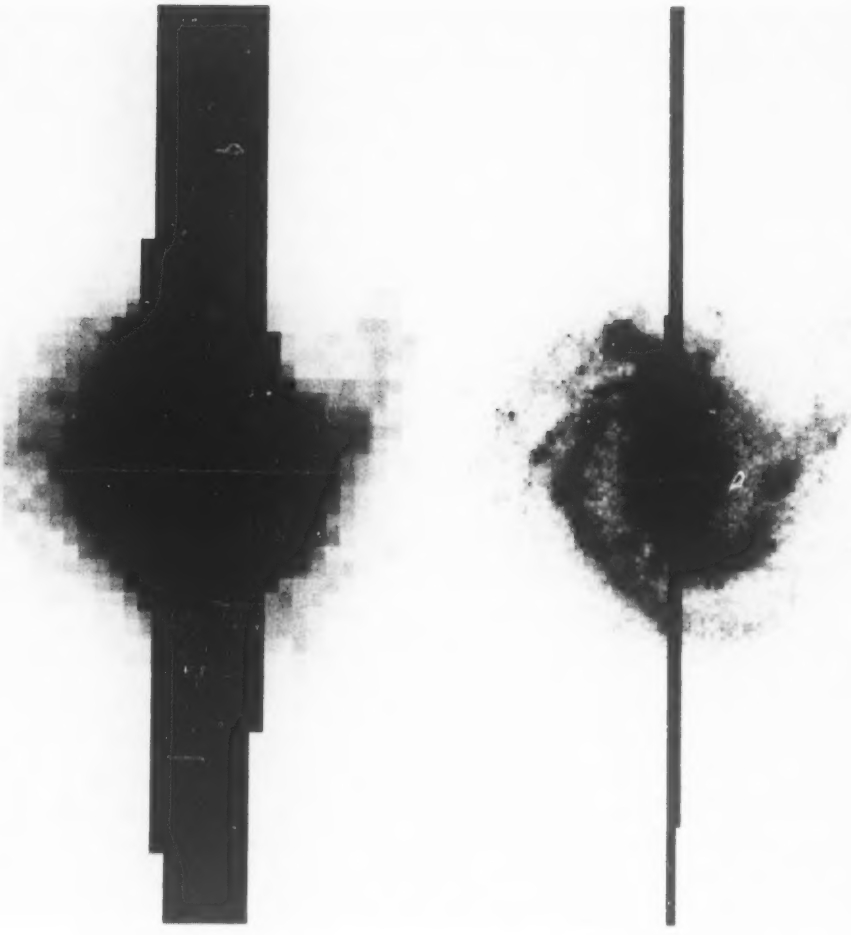
Observations that involve imaging of planets or disks around other stars will have to be deferred. Observations that search for the wobbling motion with the Fine Guidance System are possible with the existing optics.

Will we learn great things?

I am convinced that the telescope and the instruments will function, after correction, as designed. The HST should then provide at least partial answers to the fundamental questions which we have just discussed. I cannot tell you how long this take. We will have answers to some questions, as well as new questions, by the end of this year. Other questions, such as the size and age of the universe, will have to be deferred until the new instruments are ready. But, we will succeed-and on a time scale short compared to the ages of the stars.

As marvelous and as difficult an achievement as the fulfillment of this promise will be, I personally will be disappointed if this is all that HST does. I believe that the most important discoveries will provide answers to questions that we do not yet know how to ask and will concern objects that we can not yet imagine.

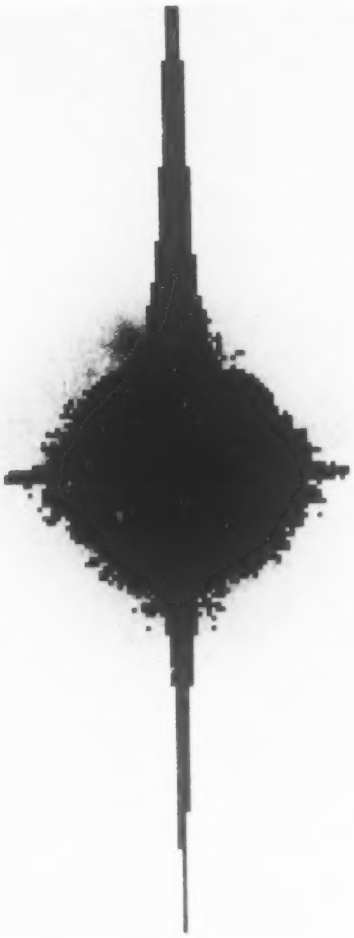
In my personal view, a failure to discover unimagined objects and answer unasked questions, once HST functions properly, would indicate a lack of imagination in stocking the Universe on the part of the Deity. All of the scientists in the HST program share a common faith–a faith that sustains in the face of temporary setbacks–a faith that we will not be disappointed, that there is more in the universe than is in our theories. I hope very much that you will invite us back to share these discoveries with you in happier times.



Quasars are the most luminous known objects in the Universe. They are often a thousand times brighter than our entire galaxy, but their most astonishing feature is that this energy is generated in a volume not much larger than the solar system! Quasars are typically at large distances (billions of light years), so we cannot study their surroundings in much detail because of the blurring caused by the Earth's atmosphere.

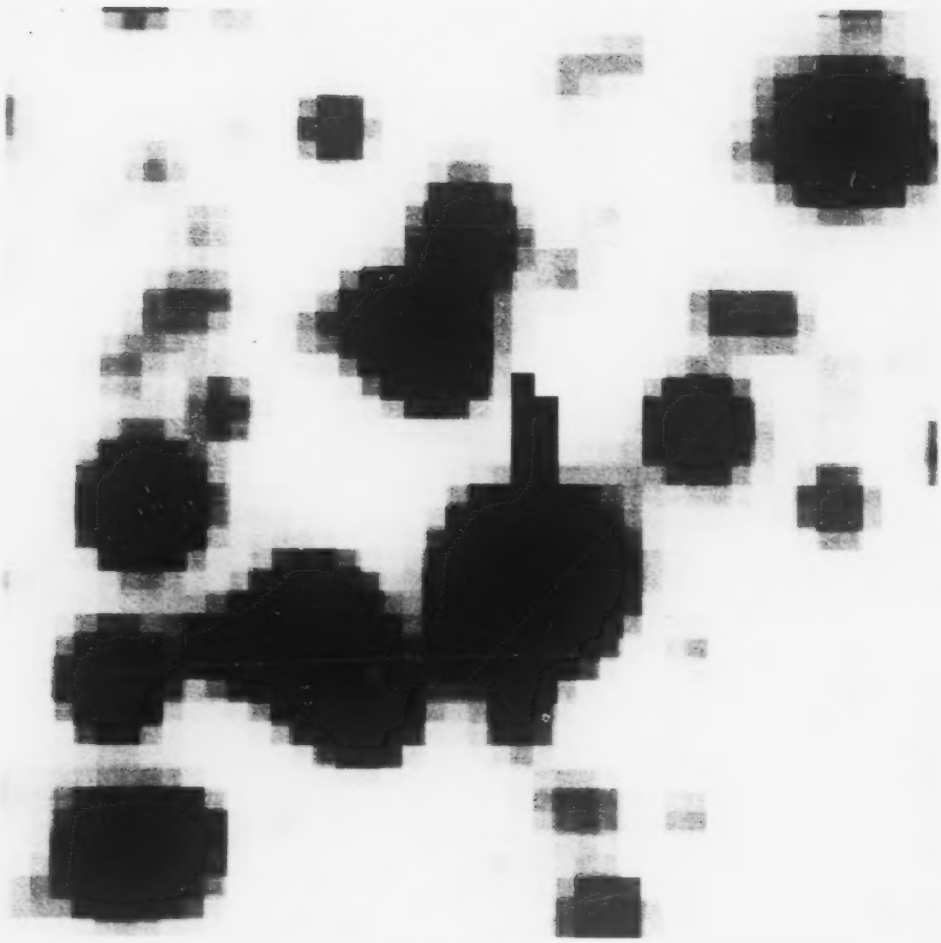
This figure is a computer simulation of observations of a famous bright quasar (3C 273) viewed by a ground based telescope (left) and the Hubble Space Telescope (right). Most astronomers believe that quasars reside at the centers of galaxies; this image shows the appearance of a spiral galaxy like the Milky Way (our galaxy) if such an object surrounded this quasar. The turbulence in the Earth's atmosphere spreads the light from the quasar so much that this galaxy would be undetectable with ground based telescopes.

Simulations produced at the Institute for Advanced Study by John Bahcall and Don Schneider.



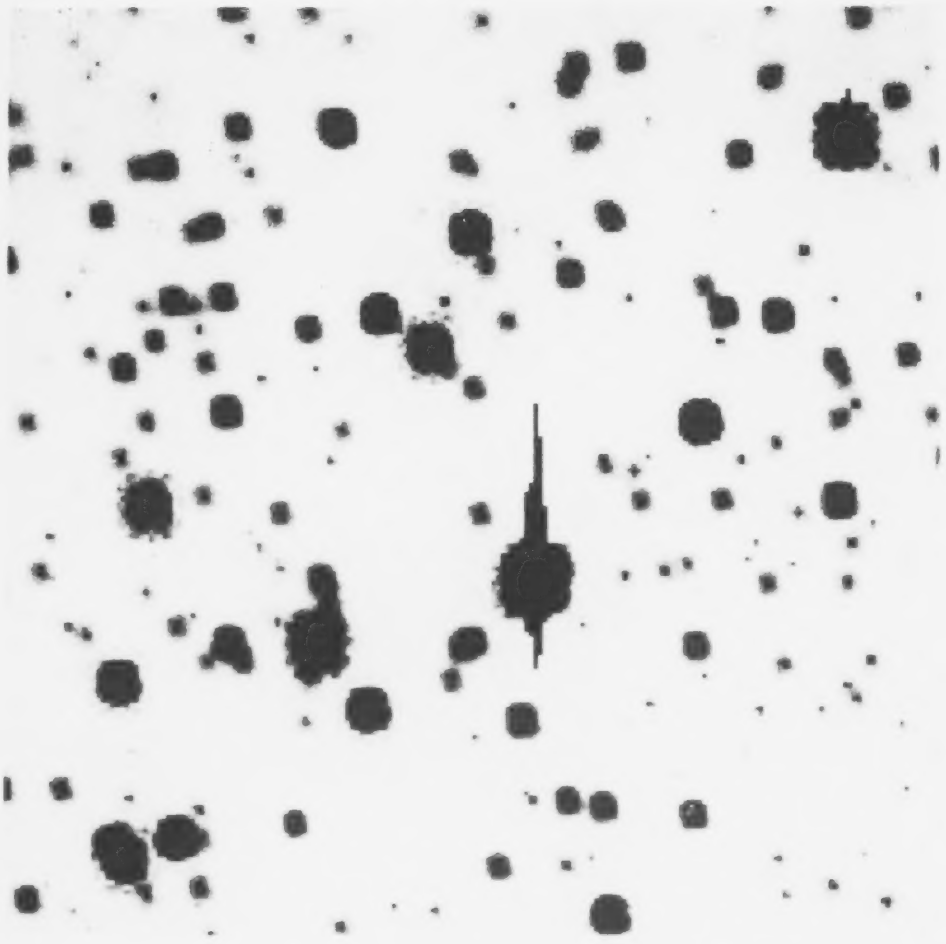
This is how the previous simulation of 3C 273 would appear with the measured HST optics through the Wide Field Camera. Note that the characteristics of the galaxy are not discernible in this image.

The reproduction shown here was made using processing equipment developed at the Institute for Advanced Study by Don Schneider, David Saxe, and John Bahcall.



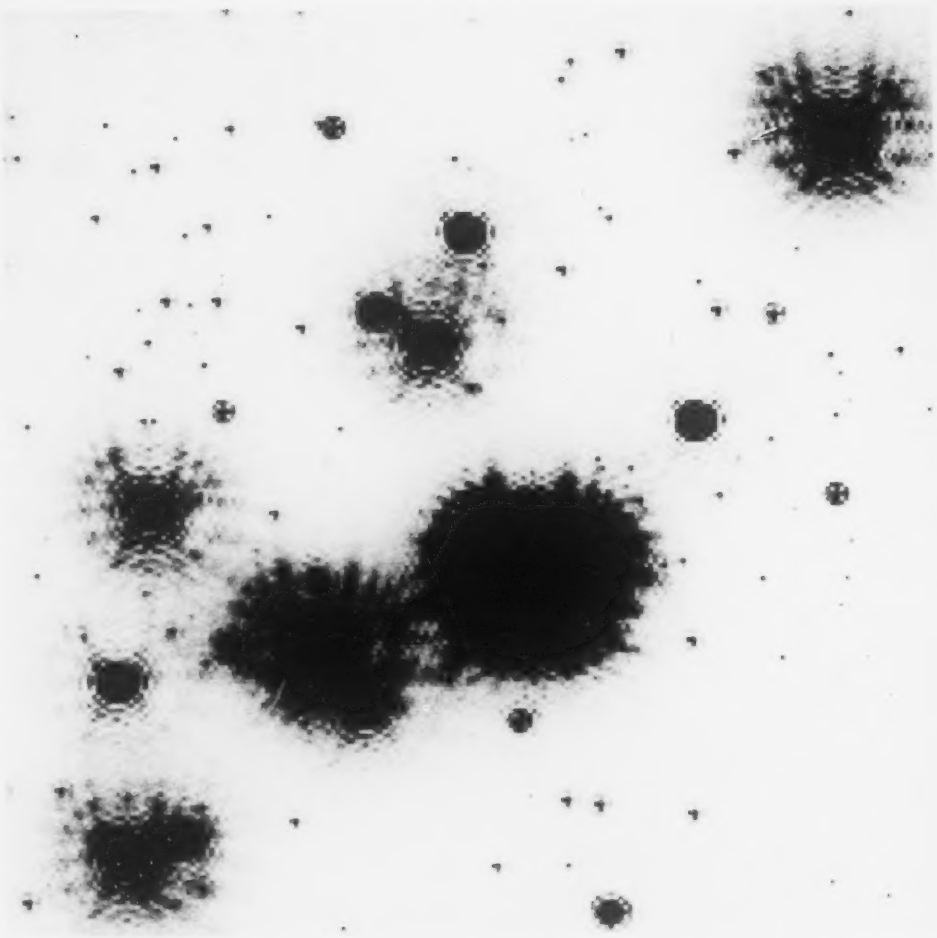
This is a simulated image of the central 8.6 arc seconds of the Galactic globular cluster M13. The seeing in this picture is 0.5 arc seconds, a value rarely, but occasionally, achieved with ground based telescopes.

The reproduction shown here was made using processing equipment developed at the Institute for Advanced Study by Don Schneider, David Saxe, and John Bahcall.



The same region of M13 as viewed with the planned HST optics through the Planetary Camera. The exposure levels are identical with the ground based data.

The reproduction shown here was made using processing equipment developed at the Institute for Advanced Study by Don Schneider, David Saxe, and John Bahcall.



The same region of M13 as viewed with the measured HST optics through the Planetary Camera. The exposure levels are identical with the ground based data.

The reproduction shown here was made using processing equipment developed at the Institute for Advanced Study by Don Schneider, David Saxe, and John Bahcall.

The CHAIRMAN. Would the members please return immediately? We'll be about 15 minutes, because we've got to conclude, so just recess.

[Recess.]

The CHAIRMAN. The committee will reconvene. The other members are working their way back. Again, it was a double vote; we can't help that.

I think what would be constructive for us, if I may, all of your statements, of course, will appear—I'll ask unanimous consent that all of your statements appear in the record, and I agree to the unanimous consent, but I think what would be helpful to us, if the others arrive back here, hopefully, is we want to get on the record—and I think you started to do that, Dr. Bahcall—the point of view, coming back, I guess, 360 degrees, you might say, from where we started out this morning, that there were levels of technology and levels of achievement that were planned when the telescope was designed.

And I'm sure you folks worked and said, "Well, these are the particular things we're going to attempt to do on that," and therefore the telescope was designed accordingly. Now, the question I think that's very important to the American people at this juncture, because we asked them is this a dud or not a dud, and so forth, is that as they've explained that they would hope to be able to work out a methodology by 1993 to improve the cameras, change lenses, and so forth, and get back up there and install them, do you see from your professional and technical expertise that the Hubble can and will do what we originally thought it was supposed to do, after making these changes?

Dr. BAHCALL. Yes, sir, I do. I don't have any doubt about that.

The CHAIRMAN. Will it be able to do everything that you had envisioned in its original design?

Dr. BAHCALL. Well, sir, my original involvement with the program was in 1973, and at that time I was convinced that we shouldn't have a telescope any smaller than three meters. The Congress instructed us in 1975, I believe it was, to come back with a less expensive program and to seek international involvement, so there were certain programs that we couldn't do with a 2.4 meter telescope that we could do with a three meter telescope just because it was more efficient, and we had even hopes for a larger program.

But since the design of the telescope was finalized somewhere around 1977 and 1978, those programs, I think, we will be able to do once the optical correction are made that NASA's planning to make.

The CHAIRMAN. But where I'm coming from, again, for clarity in the record, the Hubble as it was finalized would have achieved certain goals if the aberration didn't take place. At least, as far as we knew, right?

Dr. BAHCALL. Yes, sir.

The CHAIRMAN. Now, the question that's before us is two-fold. As we get further into this situation, we will have to ascertain what, if any, additional costs are involved and all the other things that would go with it, because I think what the American people are going to say, and see if this makes sense to you, that we have a 15-

year program, we designed a machine to do particular things, we can't do the things we wanted to do up front because of this problem. That's correct, I believe, is it not?

Dr. BAHCALL. Well, we can't do some of those. We can do some of the things.

The CHAIRMAN. Okay, we can do some of them but not the optimum that we had planned on doing.

Dr. BAHCALL. That's certainly correct.

The CHAIRMAN. All right. Now, if NASA does its bit and the Congress goes along and approves it in, say, in 1993 or thereabouts or whatever, and we go ahead and we make the changes that were discussed today as far as the mirrors and lenses were concerned on the new second generation equipment to come in, do you see when that's achieved, assuming it's achieved correctly, that we will be able to get the same yield out of the Hubble telescope, maybe over a different period of use in time, but within that 15-year period, that we would have gotten out of it if the aberration had not taken place?

Dr. BAHCALL. Sir, I think integrated over 15 years that the program will be essentially what we had promised the American people that we would do.

The CHAIRMAN. Do you see the import of that now?

Dr. BAHCALL. I certainly do.

The CHAIRMAN. And the next common denominator to that issue is going to be if that's determined, if that's correct, if that's determined to be correct, then in that instance, what, if any, additional cost or how much additional cost is involved?

Mr. BAHCALL. Yes, sir, but I would like to make a comment with respect to General Allen's investigation, which I think is important in determining whether the hypothesis from which you start is correct. You start from the hypothesis that the corrections that NASA makes will remedy fully the problem that we have, and that's the hypothesis that we're all working from now, but I think it's an extremely important aspect of General Allen's investigation to find the smoking gun and to identify exactly what happened, because that will make it possible to make these corrections essentially exact. Otherwise, we will depend upon rather imperfect measurements in orbit.

So that's an aspect of his investigation which wasn't touched upon by the committee this morning, but it's a very important aspect for us technically.

The CHAIRMAN. So what you're saying, basically, I think what I understand what you're saying now, you're saying if we can get the exact technical background data as to what happened and can measure it and so forth, that would give you the better tools to work with to improve the second generation instrumentation and so forth. Is that a fair commentary to make?

Dr. BAHCALL. That's precisely it, sir, and it's an answer to a question which was asked of General Allen this morning, what good does it do us to find out what happened; isn't the only thing that we're interested in is seeing that it doesn't happen in the future? For us, in order to ensure that we——

The CHAIRMAN. That's an important dimension. I hear what you're saying. That's a very important dimension.

Dr. BAHCALL. Yes, sir.

The CHAIRMAN. One of the things we were just talking about up here, we're going to put together a document to forward on to Admiral Truly and so forth integrating some of these additional ideas that the committee wants them to expand their charter on. But your point is well-taken. You're saying that if we can get the exact technical data or exact as possible, it will be helpful in deciding how you go ahead and improve from there. I understand that. All right. We'll do that. We'll see that that's done.

Is there any other particular statement that anyone would like to make for the record at this point or an observation or a comment? I know you've come a long way, and it's been a trying day, but it's been a productive day, I believe.

Dr. BAHCALL. We've learned to understand, sir, how repeated delays can occur in the space telescope program.

The CHAIRMAN. We've learned how repeated delays can take place in trying to get a bill through on the floor of the House, too, I agree with you.

Dr. BAHCALL. That's precisely right.

The CHAIRMAN. I didn't miss that, Doctor.

Dr. Stockman, do you have anything else you want to add at this point?

STATEMENT OF DR. HERVEY S. STOCKMAN, JR., SPACE TELESCOPE SCIENCE INSTITUTE, BALTIMORE, MD

Dr. STOCKMAN. Well, Mr. Chairman, thank you for inviting me here to address the committee, and all I'd like to say in addition to the written testimony which I've submitted, is, in summary, we've analyzed the science program that we received both on behalf of the general observers and the guaranteed time observers, who were the original scientists on the program, for the impact of this and have broken it into——

The CHAIRMAN. Is that in your testimony, too?

Dr. STOCKMAN. Yes, sir.

The CHAIRMAN. Good.

Dr. STOCKMAN. And have broken it into the amounts of those programs which are still viable and those which ought to be deferred until new instruments are put in with compensating optics, and what we find is, and, of course, this is just an estimate, because it's based on statistical analysis and not a program analysis, is that over half of the observations are viable, 56 percent, in particular, and as much as 33 percent of the original program can be executed more or less as originally planned with a relatively minor impact on the data quality, and that's generally in the area of the ultraviolet, as was mentioned before.

Based on that, for the general observer program, we're going to reconvene the original peer review panel, present these results to them as well as the desires and the assessments of the individual investigators that had originally proposed these programs, and then reshape the first year of observations based on the recommendations of the peer review panel.

We're confident that we have a first rank science program for the first year since we had over-subscribed for the first year unin-

tentionally, and some of these programs are going to have to be extended a bit because of some of the loss of light that Dr. Bahcall discussed, and so we're also confident that as we go out for the solicitation for the second year of observations with the information having to do with optics, that we can have a first-rank science program for the second year as well in anticipation of the replacement of the wide field/planetary camera.

[The prepared statement of Dr. Stockman follows:]

TESTIMONY
BEFORE THE
SCIENCE, SPACE, and TECHNOLOGY COMMITTEE
of the
US HOUSE OF REPRESENTATIVES
by
DR. HERVEY S. STOCKMAN, JR.
DEPUTY DIRECTOR, SPACE TELESCOPE SCIENCE INSTITUTE

Chairman, I thank you for this opportunity to present to the Committee on Science, Space, and Technology the status of the early HST Science Program in the light of our current knowledge of the HST optics.

As you may be aware, the Space Telescope Science Institute is responsible for the conduct of the HST science mission following the seven month commissioning period. As part of that task, we have solicited proposals from the international astronomical community; we have convened an independent scientific committee to review these proposals and recommend the most outstanding and critical programs; and we have approved approximately 170 programs with Principal Investigators from many states and countries. We have also planned to implement the scientific programs of the Guaranteed Time Observers (GTOs) who assisted in the early definition of the mission and the development of the scientific instruments. By NASA policy, these astronomers may use a portion of the early science mission to address many of their original scientific goals.

The Institute has devoted much of its effort, starting long before launch, preparing the resulting 300 programs involving tens of thousands different observations: from creating the context for their submission to ensuring that the detailed second-by-second science plans can be specified and delivered to the Payload Operations Control Center at Goddard Space Flight Center.

The current optical imaging quality will seriously impact most of these science programs. As has been previously stated, high resolution imaging of faint stars and galaxies has been severely compromised, although some high contrast scenes can be recovered using sophisticated image analysis techniques. Most of the other science instruments are also not optimized for the broader image profile, which results in significant loss of light at their apertures or resolution in their spectra. Thus, we anticipate that most of the science programs will need to be reassessed and revised to meet their original goals.

The Institute has begun to review the entire approved observing program. As the first step in our review, we have completed a statistical analysis of the combined General Observer and Guaranteed Time Observer programs for Cycle 1, the first year of normal science operations scheduled to start in January 1991. Using the details of individual instrument usage for each observation and the available image quality data, this analysis considers how much additional time would be required to achieve the intended data quality. Observations which require more than 5 times the original time are considered to be severely impacted and are generally no long viable. Other observations should be viable, but may require additional time to achieve their scientific goals. In summary, our analysis finds 56% of the combined General Observer and Guaranteed Time Observer programs are viable. As much as 33% of the original program can be executed as originally planned with only a minor

impact on their data quality. These will form the basis for the early portions of the science program. Given the intentional oversubscription of available time within the approved program and the need to increase the time for the more strongly impacted and still viable science observations, we are confident that we have the basis of a first-rate science program for the first year of science operations.

We have also begun a more detailed analysis of each observation to characterize the impact in terms of the additional time required to obtain the original scientific goals. We will also solicit the assessments of the Principal Investigator in terms of recommended changes to their programs. Both the technical and scientific assessments will be provided to the original review committee for their advice as to which programs to continue and perhaps augment. We expect to notify the General Observers of the results of these deliberations in October. Some of the programs suffer relatively little impact; and we will continue to implement them in order to begin normal science operations in early 1991.

The many astronomers who use the Wide Field Planetary Camera will find their programs most adversely affected. These analyses indicate that most of the planned observations require long exposures to achieve the required sensitivity. These faint scenes are particularly obscured by the current optical quality of the HST optics. Such observations will need to be deferred until the replacement Wide Field Planetary Camera is installed in the Hubble in 1993.

In some instances, it may be possible to utilize advanced image processing techniques to recover some of the lost resolution in images obtained with the current Wide Field Planetary Camera. NASA has convened a panel of image processing specialists from a wide variety of disciplines to assess the possibilities; and the Institute is testing routine image reconstruction techniques on the early Hubble images and soliciting advice from the astronomical community. Within a few months, we will better understand what types of Hubble images will be amenable to computer augmented resolution.

In conclusion, we are in the process of reshaping the early science program for the Hubble Space Telescope. While most programs requiring very high resolution will need to be deferred until the replacement or advanced instruments are installed, more than half of science programs can reach their original goals. As we better understand the performance of the Hubble Observatory, we will be in touch with the astronomical community in our solicitation for the second year of science programs. We are confident that first rank science will be accomplished with the Hubble in the interim between now and the installation of the replacement camera. Using that camera's internal correction of the optical aberration, the Hubble will then begin to address the remaining goals for which the telescope was originally designed and which continue to be the dreams of the astronomical community and the American public.

The CHAIRMAN. Would anybody have any idea if—suppose the replacement takes place in 1993. How long will it take from there, two, three years, to be able to get the added capabilities?

Dr. STOCKMAN. Well, sir, if I might address that, I think that the actual check-out of that camera in the spacecraft will be a matter of weeks to months and that the science program, given that the rest of the observatory is going to be relatively well-understood at that point, will be able to begin immediately using that camera. So negligible delay compared to the time between now and its replacement.

The CHAIRMAN. How long will it take to produce that camera, manufacture it? Does anybody know?

Dr. STOCKMAN. Sir, I believe that it was intended to be completed in the summer of 1992, originally, but you really should be asking Dr. Bless.

The CHAIRMAN. We'll ask them, yes, okay.

Now, Dr. Bless?

STATEMENT OF DR. ROBERT C. BLESS, ASTRONOMY DEPARTMENT, UNIVERSITY OF WISCONSIN, MADISON, WI

Dr. BLESS. Yes, sir, I would like to refer to my written statement, and I would like to add one or two comments which have been touched upon by the committee but not with enough force, it seems to me. If you'll forgive me, as one of the old fogies on this project, I would like to inject a touch of history of this.

I've been involved with the project since the early 1970s, and this whole business did not happen in a vacuum but happened with some very definite attitudes and atmosphere. The project was sold in the 1970s before the Shuttle had flown, as you recall, when NASA could still speak quite unrealistically about it. At that time, there were going to be 50 flights a year, the cost of the near earth orbit was about $100 a pound, it was a space bus, you know, just hop on and go up.

So the attitude was, well, obviously, if that's the case, then if something happens to the space telescope, all you do is go up, bring it back down to the ground, and fix it, and if that's the case, then we don't need a test so much, and the test program for a space telescope was indeed very, very skimpy, and some of us spent a great deal of time trying to put tests back into the program.

So first of al , then, there was this attitude that developed from the very beginning that testing could be kept to a minimum, costs could be kept to a minimum, and therefore you people would accept it more readily. And then there are some early circumstances that I think you should remember, and that is, in the early days of the project, once it got started after 1977, Perkin-Elmer was nearly consistently behind schedule, nearly consistently over budget, and they were getting beat over the head all the time about this by Marshall.

The idea that somebody could have gotten very far by suggesting under those circumstances that we spend a certain amount of money and schedule for an additional test, it really just wasn't in the cards. It simply would not have happened. At that time, Mar-

shall was under a manpower cap, and the amount of supervision they could bring to bear on Perkin-Elmer was quite limited.

Systems engineering, which came to the fore after the 1983 crisis, was very minimal at that point. People simply weren't paying attention to these things. So it was an atmosphere in which it would have been quite difficult to get tests done, particularly if you consider the kind of tests that were involved.

The test equipment of an optical system has to be at least as good and better than the article you're testing. You were making a wonderful telescope, a very high quality telescope. The test equipment had to be at least that good. It would have been extremely expensive. What the right number is, I don't know, but it would have been extremely expensive to do a test of the primary and the secondary mirror working together which would reveal the spherical aberration.

That kind of a test just was not in the cards. Even in the ST world, in the expenses of the ST world, that would have been a very expensive test. Could a simpler test have been done? The answer is yes, but had a simpler test been—that is, a less sensitive test, a perceptive test—had that been suggested?

The response would have been, and I'm willing to bet all the cheese in Wisconsin that this would have been the response, namely that would you want to spend even a few millions and a few weeks or a month to do this simple test, this very insensitive test, when you know that we've measured this parameter that you're talking about, the curvature of the mirror? We've already done that test, it's a standard test, well-known, well-understood, it has to be carefully, it has been done carefully, there's no problems with it—this is crazy. You know, go back home. Leave us alone. That simply would not have gotten anywhere, that kind of a thing.

So this doesn't exonerate anybody or anything, but I think you have to keep this in mind when you're considering this whole problem.

[The prepared statement of Dr. Bless follows:]

Statement of Robert C. Bless, Principal Investigator of the High Speed Photometer on
Hubble Space Telescope
before the
Committee on Science, Space, and Technology
House of Representatives

Mr. Chairman and Members of the Committee:

Thank you for the opportunity to give you a preliminary assessment of the effect of the flawed images on the scientific capability of the Hubble Space Telescope.

Recently it was discovered that either the primary or the secondary mirror of the Hubble Space Telescope suffers from an optical defect called spherical aberration. This means that light reflected from the outer portion of the mirror does not come to a focus at the same point as light reflected from the inner portion. As a consequence, the telescope will not produce the sharp images which would have enabled us to view astronomical objects in unprecedented detail in both visible and ultraviolet light.

It is still too early for anyone to characterize precisely how this will affect the science programs of HST. I can, however, describe most of the considerations which enter into that assessment for all of the instruments now on board, and say a few very tentative words as to how the science capability of the instruments are likely to be affected by these considerations, and finish with the prospects for recovering some of the capabilities originally intended for HST.

Let me begin by describing the problem we have. The relevant Level 1 requirement for the optical performance of the telescope states that "70 percent of the total energy of a stellar image must be contained within a radius of 0.10 seconds of arc". Instead, the telescope delivers only about 15 percent of the energy within the 0.10 arcsec radius. Seventy percent of the energy is now contained within a radius of about 1.0 second of arc, ten times that stated in the Level 1 requirement. If the image is thought of as consisting of a narrow core surrounded by a broad skirt or wings, then sharpening the image core increases the energy in the wings; diminishing the wings reduces the energy in the core. In all likelihood one focus position will be adopted for the telescope, but it has not yet been decided which is the optimum image shape. Consequently, for this and other reasons, any estimates of the effect of the real images on HST science must be more qualitative than quantitative.

Very roughly speaking HST images will show about the same amount of detail as can be obtained by a ground-based telescope at a good site. HST images do have a sharper core than do ground images, however. This may be important in some instances.

What general scientific capabilities does HST still have? It is important to remember that we have access to the ultraviolet region of the spectrum which is absorbed by the earth's atmosphere and does not reach the ground. Furthermore, since HST is above the atmosphere, the brightness of the sky background is reduced. More importantly, images don't twinkle--don't change in brightness and don't jump around--but remain fixed in position and shape. This last has important consequences which I shall return to in a moment.

What general capabilities have been lost or seriously compromised? Obviously, HST will not be able to produce the sharp, detailed ultraviolet or visible images which were to have been the observatory's centerpiece. Another consequence of the images we have is that it will be more difficult to detect the faintest objects, since the light is not as concentrated. This affects all of the instruments on HST. Also, the telescope's ability to collect light from only one object in a field crowded with objects--to pick out a star near the center of a globular cluster, for example--has been seriously compromised. This is the case because individual star images now overlap each other rather than being well separated.

Let me make a few rather general remarks as to the consequences all this has for the science which HST can do. The images in visible light which the Wide Field and Planetary

Camera can now obtain are only a little better than those obtained from the ground and for the most part will probably not be taken. There may be some exceptions to this, however. Since the shape of an HST image of a star will not change in time, and since it should be possible to characterize that shape accurately, mathematical techniques exist which allow you to calculate what the image would have looked like if the optics had been perfect. In other words, by computing you can recover some of the information lost in the fuzzy image. This process, called image deconvolution, is most efficiently done for relatively simple scenes--a few stars, for example--and requires considerable computer time. The possibilities afforded by image deconvolution are being looked at carefully. We don't yet know just how practicable the technique will be for HST.

In any case, well more than half of the observations planned for the WFC will not be carried out, especially those requiring detecting the most detail or measuring the faintest objects. This includes most of the WFC cosmological programs, that is, observations designed to determine, for example, the content of the distant universe and its expansion rate or, alternatively, its age.

What about ultraviolet imaging? Since hardly any ultraviolet images have yet been obtained from space, HST's capability here is still extremely important and useful. Thus, many of the Faint Object Camera's UV images will yield unique data even though they will not reveal as much detail as had been planned. Perhaps half of the FOC's originally planned program can be carried out, though not with as high quality data as had been hoped.

For understandable reasons, the imaging capability of HST has received most attention in the press, but it is not the only way HST can do important science. Spectrographs spread light from a star into its constituent wavelengths or colors. Spectroscopy is a very sophisticated science and is the means by which we determine the physical nature of all kinds of astronomical objects, for example, their chemical composition, their temperature, and their velocity. The ultraviolet is a particularly fruitful spectral region for many of these studies. By high speed photometry we can measure very rapid changes in the brightnesses of various kinds of exotic objects like rapidly rotating neutron stars (pulsars) or double stars which produce intense streams of x-rays, for example. Since stars don't twinkle when observed from space, it is also possible to measure very small brightness fluctuations produced by a wide variety of astronomical objects, from nearby stars to distant quasars. No such observations have yet been made in the UV region of the spectrum.

So let me turn now from the instruments on HST which produce images to those which don't--the Faint Object Spectrograph, the Goddard High Resolution Spectrograph, and the High Speed Photometer. These instruments require that the light from a star, for example, passes through one of several entrance apertures which range in size from about 2.0 to 0.1 seconds of arc. Since HST images of point sources are now larger than all of these apertures, much of the light from a star will not enter the instrument. That means that to achieve the same data quality, the exposure times must be longer. Just how much longer depends on a variety of factors, for example, the brightness of the background, the steadiness of the telescope pointing, the exact shape of the image which is adopted, etc. It is likely, however, that increases in exposure times by factors of 2 to 6 will be necessary to obtain data of the necessary quality. In some instances, a larger aperture will have to be used as well which would result in the spectral resolution--the detail in the spectrum--being degraded.

The effect of the large images goes beyond a longer exposure time or decreased spectral resolution. Often there are bright objects near the object being studied and light from the former will contaminate the spectrum of the latter. This is another aspect of the crowded field effect mentioned earlier. Though it will not be possible to carry out many of the programs planned for these instruments, roughly half will be possible and will produce unique ultraviolet data.

The efficiency of the High Speed Photometer as well as its ability to observe in crowded fields is also adversely affected by the large images. Again, longer exposure times can compensate for the former. When images were to have been small, telescope pointing jitter would not move the images out of the photometer's entrance aperture. Now it will and as a

consequence the ability of the instrument to detect small variations in the brightness of objects will be affected. Nonetheless, we estimate that about three-quarters of our observing program can still be performed.

Finally the use of the Fine Guidance Sensors to measure precisely the positions of stars is apparently not seriously affected. Most of the observing programs planned for the FGS's will be possible.

It is obvious that the rate at which data are produced by the HST observatory will be decreased, but it is not possible to say by how much at this time.

I am sorry that I cannot be more definitive in these estimates of instrument performance. Though all of us feel sure that HST will still produce exciting new data, the fact is that until we actually try many of these observations we will not know just how well we will be able to do. At the present time the instrument teams are reviewing their test programs and their observing programs so that we can acquire the necessary information as efficiently as possible. We will not be able to begin to collect much of the necessary data until the telescope can be pointed accurately and reliably, however. Consequently I cannot give a realistic estimate as to when we will understand in some depth the affect on HST science of the images we have.

Finally, let me turn from HST's short-term expectations to its long-term prospects. Nothing can now be done to the telescope itself or to the existing (first generation) instruments to correct the spherical aberration. Replacement (second generation) instruments can correct for the image defect, however. When the particular focus of the telescope is decided upon, it should be possible to characterize the shape of the image very precisely. With this information, the second generation instruments, already under development, should be able to design their optics so as to correct for the spherical aberration and recover the originally expected image quality. For example, the second generation Wide Field and Planetary Camera should be able to produce the high resolution images expected of the original WFPC. The project now plans to speed up the completion of the new camera by about six months after which a shuttle crew will install it in HST. The hope is that within about three years, much of the imaging capability of HST will have been recovered, especially in the visible region of the spectrum.

The other two instruments under development, an infrared camera and spectrograph and an imaging ultraviolet spectrograph, can also be modified optically to correct for the image defect. When the second generation instruments are successfully installed, HST will produce the extraordinarily high quality data we all have expected.

The CHAIRMAN. It puts it in perspective.

Dr. BLESS. A very strong attitude involving testing in this program.

The CHAIRMAN. But that's also—with the terrible shortage of time we have right now—that's also a very important observation to make, because one of the criticisms that is arising now is that as we get in "these big scientific ventures," should we not be going in that direction, it's too expensive, blah, blah, the whole bit? Our resources are finite, so as to speak, and therefore we should be using it for smaller or medium-size research work and so forth and so on so that when we do make a commitment to a large machine with that kind of funding involved, then testing becomes almost essential at that point of view. Do you understand what I'm trying to say?

Dr. BLESS. Sure, sure.

Mr. NAGLE. Will the chairman yield?

The CHAIRMAN. Yes, of course.

Mr. NAGLE. I know you're short on time, but my thrust on this is probably different than most members of the committee.

What you're saying in part is that once again we find the Shuttle's "availability and reliability" to have led us down a false path. But I wonder if the panel could comment, or if you would, I'm also concerned about orbital height, and we had some discussions this morning about the Van Allen radiation belt. Is the Shuttle our vehicle of choice for these big space science projects, given the fact that it restricts us to these low earth orbits?

Dr. BLESS. Well, in an ideal world, what you would like to have is a launch vehicle that suits the project, that suits the mission, that suits the instrument you're trying to put up. What we have now instead is that you have to fit the project to the one launch vehicle.

Now, NASA is changing this, and they are using other vehicles than the Shuttle to do so, but the decision on the Hubble was made, of course, in the context of using the Shuttle. So, yes, you would like to have some flexibility. You shouldn't require all payloads to fit into the shuttle and into its capabilities.

Mr. NAGLE. And weigh not more than 50,000 pounds.

Dr. BLESS. That's right, or whatever.

Mr. NAGLE. Thank you, Mr. Chairman.

The CHAIRMAN. How about Dr. Oertel?

STATEMENT OF DR. GOETZ K. OERTEL, PRESIDENT, ASSOCIATION OF UNIVERSITIES FOR RESEARCH IN ASTRONOMY, WASHINGTON, DC

Dr. OERTEL. Mr. Chairman, I will very briefly summarize my statement. We at AURA believe that Hubble can meet its goals in part now and in the balance with new instruments. We believe that the instruments can be built to correct substantially the spherical aberration for the flaw. We think that this should not be done necessarily in the fastest possible way.

I think it is more important that it be done consistently with quality so that you be sure that these instruments will work when they're there, but, obviously, as soon as that can be done, they should be flown. The challenge of installing them in orbit, I think,

is very great, and we think it can be met, but that will require a lot of attention.

My final point I wanted to make concerns the data analysis and interpretation program, both by the instrument development teams and by the general observers. I believe that NASA should expand the scope of this program to meet the challenge of the early data so that we can get as much out of them as we can, and it should include in particular also for the support of timely preparation for the processing analysis and interpretation of the data that will come from the new instruments so that we can then save as much of the time that might be lost and to be as effective in getting the science results that all of us have been waiting for. I thank you for the opportunity to talk to you about it.

[The prepared statement of Dr. Oertel follows:]

Testimony
before the
Science, Space, and Technology Committee
of the
US House of Representatives
by
Dr. Goetz K. Oertel
President, AURA, Inc.
July 13, 1990

Mr. Chairman and members of the committee, I thank you for the opportunity to testify before this Committee. I represent AURA, Inc., a not-for-profit corporation that is dedicated to astronomy.

AURA operates national astronomy centers: the Space Telescope Science Institute in Baltimore, Maryland for NASA, and the National Optical Astronomy Observatories in Tucson, Arizona for NSF. These centers grant astronomers access to telescopes based on the merits of their proposed work. Twenty-one premier US universities are AURA members and help oversee its operation.

AURA's mission is the pursuit of excellence in science and in service to the astronomy community. From that point of view, I will comment briefly on the status of the Hubble Space Telescope, on what it can do now and in the future, and on plans for getting there from here. I will close with a few observations.

What is the capability of Hubble?

You have heard about spherical aberration. It means that images from the two cameras on board are less sharp. Also, the light that

is fed to the other instruments is less intense, or more diffuse, or both.

How does that affect the science? Some can be done, some must wait. For example, the Wide Field Planetary Camera depends on extremely high quality focusing to take advantage of the lack of atmospheric blurring and to compete favorably with new ground-based capabilities. The exciting cosmology with that camera must therefore wait for better focus. By contrast, Hubble ultraviolet imaging and spectroscopy capabilities remain exceptional. They have no ground-based competition.

The full answer depends on the sub-field of astronomy, on specific objectives, on instrument modes, and so forth. The Space Telescope Science Institute is reviewing the full range of effects. Peter Stockman will describe that work for you. In sum, Hubble can do some, but not all of its job now.

What can be done?

The missing capabilities can be restored; Hubble can produce science now; and astronomers can prepare for the day when Hubble's full capabilities have been restored. In particular:

New instruments make it possible to bring Hubble pictures into sharp focus because spherical aberration can be corrected. As long planned, NASA is already developing two new Hubble instruments and a replacement Wide Field Planetary Camera.

NASA guaranteed certain shares of the observing time to the science teams that developed the Hubble instruments. Most will get at least some of the results they have hoped for soon. Similarly, we selected astronomers from most States and from fourteen foreign countries as General Observers on Hubble. Approximately half of them should be able to make their observations with Hubble during the next year.

Science teams and guest observers who depend upon the sharpest imaging can prepare themselves now for working with data from the replacement camera for Hubble. They can use sample data from the present Hubble to test and verify the complex techniques by which scientific measurements are extracted from the images. In some instances, they can use modern image processing on images from Hubble to obtain results that approach the sharpness of the fully restored Hubble.

What should be done?

Hubble can do its intended job. Some of that can be done now, the rest with the already planned new instruments. Here is how this can be brought about.

First, NASA should continue to develop new Hubble instruments as planned. Their objectives had been to improve Hubble's original capabilities and scope. Now the new instruments have become critically important: they will generate the very first super-sharp images and produce unique science. The science teams should develop the instruments as rapidly as is consistent with quality.

Second, the astronauts should install the instruments in Hubble as soon as possible after they have been thoroughly tested. This will require unusual doses of training and quality assurance. The nature of the spacecraft, and the delicacy and physical dimensions of the instruments, make this possibly the toughest task undertaken by astronauts. The critical importance of the new instruments to the performance of the Hubble telescope will put unusual pressure on these women and men.

Third, NASA should operate Hubble so that it can do the science it is already capable of. The Space Telescope Science Institute will: define and publicize the present capabilities of Hubble and of the observing modes of the instruments; assess the feasibility of the previously selected first "cycle" of guest observer programs; and receive and review the second cycle of guest observer proposals as planned.

Fourth, NASA should support data analysis and interpretation by instrument development teams and by General Observers. NASA should expand the scope of this program to meet the challenge of the early data. It should include support for timely preparation for processing, analysis, and interpretation of data that may be acquired with the new instruments when installed.

Other comments

Hubble may be the most complex and technically challenging civilian robot satellite ever devised and flown to space. There is much to be learned from what went wrong--and from what went right.

Scientists and engineers met most of Hubble's technical challenges, many brilliantly. All scientific instruments are working well. Despite early problems, the telescope acquires its often elusive targets and points at them with the required great precision and stability. We met the extraordinary challenge of commanding,

controlling, and interrogating the spacecraft in orbit. Countless subsystems in orbit and on the ground are doing their jobs. Quality was designed and built into these subsystems. The exception, spherical aberration in the optics, represents a flaw in that subsystem. Because it affects Hubble's performance, it raises questions about systems integration and about quality.

NASA has asked a panel under the leadership of Lew Allen, Director of the Jet Propulsion Laboratory, to investigate. Lew's technical and management experience and his personal integrity bode well for a thorough and objective investigation.

I hope that he will not mind if I point to a subtle but possibly important factor in science projects: extra motivation. All team members take pride in their jobs and want the project to succeed. Professional team members also have their jobs and possibly their careers at stake. Scientists are no exception. However, they have an extra motivation IF they want to USE the project for THEIR OWN research, AFTER it is becomes a success. This has two favorable effects for the project: dedication and, most importantly, concern about the SYSTEM. To a scientist, the reward depends on whether the system works and continues to work as a whole.

This extra motivation makes scientists worry not only about their own tasks but also about those of other team members. They ask many questions. They become a pest. But they may save the day if they discover something that would have been missed. This extra motivation, or "x-factor," does not guarantee success. But it helps. It may not be a coincidence that Hubble's instruments and the ground systems that were under the aegis of scientists perform so well.

The Hubble review can strengthen future science programs. It should identify what went right as well as what went wrong. It should suggest what to improve, and how to "play to our strengths," technically and managerially. The review could also harm future programs. For example, it should not result in stifling or punitive measures, or in over-managing or micro-managing the scientists and engineers in NASA and its space science team.

My final comment concerns people. Organizations and processes do not make people work, rather, it is the other way around. Hubble is no exception. One group of people is especially affected: scientists at our universities and elsewhere who have devoted themselves to Hubble and who were relying on Hubble data for their research. We must find ways to keep them on the Hubble team while they wait for the new instruments.

Summary

Hubble can meet its goals and objectives, in part now and in part with new instruments. Astronomers will work with NASA to get from Hubble the best science it can already do, and to prepare for the day when its full capabilities are restored. Science teams can build instruments that correct for spherical aberration. The astronauts can meet the challenge of properly installing the instruments on orbit. AURA and the Space Telescope Science Institute will do their parts to support NASA's space science team. Lessons from the experience can benefit future science projects.

The CHAIRMAN. I thank you.

Are there other questions?

Mr. WALKER. Mr. Chairman, just a couple of brief questions, if I could.

Are there any of you who had any doubts whatsoever about the correction that NASA proposes to make to take care of the problem? Do any of you have any concerns whatsoever about that corrective strategy?

Dr. BAHCALL. Sir, if I could answer that in part, the diagnosis of the problem has been a team effort, most of the members of the team not having been assigned that task but everybody working full time to try to understand the problem. I think there's a general consensus that the problem has been understood and that the solutions that have been proposed are sensible and in fact almost necessary solutions.

I think the one concern we have is to get the most accurate data so we know that the correction will be as precise as possible.

Mr. WALKER. Sure. But in terms of the strategy at the present time, none of you doubt that that's the right strategy? Do you know of any doubts within the scientific community about that strategy?

Dr. BAHCALL. You also should know that NASA is all the time seeking to find better and quicker ways of achieving the same goal so that they're not limited to the solutions that have so far been carefully explored.

Mr. WALKER. Well, except that we have heard today how they at the present time intend to go about taking care of it. And I just want to make certain that we don't end up with somebody coming back to us three years from now saying, oh, you know, "We thought this should have been done some other way." I'm just asking the question. Do any of you know of anyone out there who is concerned about the corrective surgery that NASA intends to perform?

Dr. BLESS. Well, I think this is the only thing that can be done. I would remind you of something I'm sure you're all aware of. On-orbit replacement is not a trivial thing. You can have problems there, and we take our chances. But as far as the overall strategy goes——

Mr. NAGLE [assuming the chair]. Will the gentleman yield?

Mr. WALKER. Sure.

Mr. NAGLE. I've been reading some scientific thoughts and suggestions that in fact there is a minority, admittedly, of scientists who are suggesting that the better course to do is to go up and bring the thing back and make the repairs on earth. Of course, the down side to that is that your repairs may be more accurate, but you lose the three years of observation while you're getting the thing back down. You do acknowledge that there are those within the scientific community that are advocating it?

Dr. BLESS. Yes, that was looked at. In fact, that was the original plan that when ST needed refurbishment, it would be brought back down to the ground. That was in the original plan for the project. When that was looked at in some detail, which was not until well into the 1980s, it turned out that the cost to do that was extremely high. You were getting to the point where you would wonder

whether or not you shouldn't just build another one rather than bring it down. So at that time, then, the project changed its strategy and said, okay, we will rely on entirely on orbit replacements. Bringing it down is a very expensive enterprise.

Mr. NAGLE. I thank the gentleman for yielding.

Mr. WALKER. One final question. Are there any of you who have some concerns about the fact that during the course of this project it was managed by at least two different teams of people or two different centers?

Dr. BAHCALL. Sir, could I suggest you rephrase the question? Could I suggest you ask if there are any of us who don't have such concerns? [Laughter.]

Mr. WALKER. Well, in other words, I mean, that's one of the things that this committee, I think, is going to have to explore in all of this. It's been a long-standing concern about the NASA management style, and it's one of the things that I think when all is said and done we are going to have to look at in some depth, and so I just wanted for the record that reply. That gives me a pretty firm reply that it is something that we probably ought to be concerned about as we study this problem and what solutions need to be put in place to deal with it.

Thank you, Mr. Chairman.

Mr. NAGLE [assuming the chair]. The gentleman from Pennsylvania?

Mr. WALGREN. Thank you, Mr. Chairman.

Mr. NAGLE. He's gone. We've got more time now.

Mr. WALGREN. We can really go into it now, couldn't we?

Mr. NAGLE. We won't tell him what we did here, either. We're just going to go right ahead here. [Laughter.]

Mr. WALGREN. Dr. Bless, there was a Science Working Group that advised on this project throughout. Were they advising tests that were not conducted? You indicated that there was an atmosphere early on that no one would propose other testing.

Dr. BLESS. Yes, there was and still is a Science Working Group, which is made up of the principal investigators for the instruments, plus two optical scientists who were charged with looking after the telescope aspects, plus so- called interdisciplinary scientists to make sure that the telescope met the requirements to do spectroscopy, to do imaging, to do so on, and Dr. Bahcall is one of those.

At the time, we were probably remiss, but I recall vaguely—I haven't looked up my notes to see how accurate this is—but I recall only vaguely discussions concerning the testing of the mirrors, of the primary and the secondary mirrors. We knew that they weren't being tested together as a unit, but that didn't bother me, and I don't recall any committee bother about that. I don't think we ever said anything about that.

I believe that we felt that the measurements that were being made, done properly, would certify the quality and relevant parameters of the telescope. The caveat there was "done properly," and apparently we were remiss in not making sure perhaps that they were done properly. But we did not, as I recall, as a group, we did not raise any serious objections to what was going on technically within Perkin-Elmer at that time. At least, I don't recall any.

Mr. WALGREN. You described the circumstance where Perkin-Elmer was behind, or somebody did, behind and behind and behind, and the group at Marshall was extreme in their ability to be involved in this in a hands-on way, I gather, and they faced a manpower cap imposed by the Reagan Administration to try to hold down costs. Can you describe the degree of that limitation? When you say that they were limited, what would they have wanted to be doing in terms of interaction with Perkin-Elmer from the Marshall level compared to the degree of contact that they actually had with the project?

Dr. BLESS. You are asking about things that I don't know very much about, because my perspective is from quite a different point of view, and my information comes from observations of quarterly reviews and talking with people and trying to get information about various things; however, I can say this.

I think what they wanted to do was what they finally did do in late 1982, I believe it was, where they sent a group of about 20 people from Marshall in residence at Danbury to oversee what was going on, to help them with their schedule development, to help them with their management, and so on. A large number of people spent a couple of years there, as I recall, and I suspect they would have liked to have done that earlier had they been able to do so.

Mr. WALGREN. By that time, this particular aberration would have been in the system.

Dr. BLESS. I think that's correct, yes.

Mr. WALGREN. I can't get out of my mind, if the chairman will give me the time, that this may go back to something that prior practice would not have tested, and by that I assume from the idea that this is not a ground-breaking effort to mill a mirror in a certain shape and that there's a lot of confidence, as you said, that the mirror had been milled to the directed specifications and that because it was going into a new application, use in non-gravity circumstances, that the testing of the optics of the operating system were relatively difficult.

But it would seem to me that if somebody were starting with an abundance of caution, in view of the fact that the reason we generally have confidence that the mirror will be milled properly is it's usually not too difficult a job to get back at it and correct it on ground based systems, and that since this one was not able to be tested in an end-to-end situation, that you would positively look for more assurance in the process than you would have were you making a mirror for ground based application, and yet that does not appear to be done here.

Dr. BLESS. Until the Allen panel finishes its investigation, that is hard to answer, but, for example, one question that you might ask is, one group of technicians went in and set up the test equipment, made the measurements, and got an answer. Since this is the only chance that you're going to have to get it right, you might have suggested, "Well, maybe you should tear down the test set-up, ask another completely different group of technicians to come in and make the same test, and see if you get the same answer." That might have been something worth doing. Whether they did that or not, I don't know.

Mr. WALGREN. But even in this instance, we know that the subsidiary test that Dr. Allen, I think it was, referred to gave a different answer than you would directly expect, but because that test was not designed to be a direct test of the primary mirror, that difference was sort of explained away, and so not only did you not bring in the second group to independently do it with a new set-up, but you actually had numbers that were not corresponding, and yet it didn't raise the flag to the level of pursuing a second test.

Dr. BLESS. You're now getting into matters that I have no direct knowledge of, so I really can't comment.

Mr. WALGREN. Well, it just strikes me that when you're going into an unprecedented area that sort of rules out some of the normal retroactive testing that you can do with ground based systems that then you ought to be positively looking for other test checks, and there seems to be no evidence that even the Scientific Working Group was looking for other ways of assurance that the system was proper.

Dr. BLESS. Your comment about the Science Working Group is correct, unfortunately.

Dr. BAHCALL. May I add, Mr. Walgren, a comment here? I was not assigned any responsibilities on the Science Working Group with regard to the other major Perkin-Elmer contribution, the fine guidance system, but by accident, because of a certain expertise I had related to that, I accidentally discovered a design error in the sensitivity of the fine guidance system. That design error would have resulted in the telescope being not able to study many of the objects that we wanted to, because we couldn't point the telescope reliably in the directions of many of the objects.

It was an accident that I discovered this error, and it was a difficult situation to get through the project the need for re-examining the calculation. That eventually was done, and after sufficient proof was offered that there was an error, the project recognized the error and made a major redesign and rethinking about the specifications for the fine guidance sensor sensitivity.

That occurred in the period, as I remember, of 1980 to 1981, and what it is intended to simply to illustrate is that all of us felt free, indeed obligated, to explore whatever areas our particular expertise justified our investigating, and we did so whether or not we had any responsibility or indeed whether or not we were told we were permitted to do so. In some cases that was useful, in some cases it wasn't.

It's my personal belief that had any of us had the simple idea of doing a knife-edge test, which is the non-invasive, very simple standard test that you would do on any ground based mirror, had any of us had that idea, unlike by colleague, Bob Bless, I think that if one of us had had that idea at the time and had jumped up and down and screamed enough about it, we probably could have gotten it through.

You can't test that in retrospect. The situation was, as he described it, not receptive to new ideas or to suggestions, and there was a general conviction which we had been assured that the mirror was perfect, and it was the best ever, and it was better than specs. But I think I have to, as a member of the Science Working Group and as a scientist, I think we all bear equal responsibility of

not having had 100 percent foresight. I think if we screamed loud enough, we could have gotten it. Unfortunately, none of us had that simple idea.

Mr. WALGREN. Dr. Allen's testimony described several simple tests, inexpensive, that, if the assumptions people are operating on now bear out to be true, would have revealed that flaw, and I gather from your testimony that none of those simple characteristic type tests that Dr. Allen now points to were recommended by anybody associated either directly or in your instance with related expertise and related contact to the project. None of those tests were recommended. Is that your understanding?

Dr. BAHCALL. I don't remember them, and I have to tell you that had somebody convinced me of the utility of those tests or had the idea occurred to me, I had sufficient access at higher levels in NASA that I would have gone, had I felt they were justified, and tried to see that happen, and I think it would not have been unlikely that they would have happened. It's just that none of us had that simple idea.

Mr. WALGREN. If the chair would permit, you mentioned, Dr. Bahcall, that you ran into certain difficulty in getting the error which you found recognized by the project. Can you describe the difficulty that you had?

Dr. BAHCALL. Well, all of us make errors, all engineers and all scientists make errors. When somebody recognizes an error, you're embarrassed by it, and you're response, all of us, is, "Gee, I don't want that to come out," or "I wish that guy would go away," and I encountered some of that, but I think it took a few months, but once the problem didn't go away, the project accepted it completely, and although it was a very expensive activity and at the time it looked like it could have much greater implications than it finally did, it looked very serious and very expensive to us for a while, and the project accepted it technically.

Mr. WALGREN. I always get scared when I think of problems not going away or going away, remembering the quote from the fellow in Martin Marietta on the danger of the O-ring problem not being solved, where on one level of the project there was actually in writing on a piece of paper the admonition that they risked losing not only the shuttle, but the crew and the pad and the whole installation, and yet that problem went away.

Even though it existed on paper on one level of this development project, and it's hard to have much confidence that errors will in fact be brought through and recognizes as yours was when we see the evidence of that one with such catastrophic consequences not having been brought through and recognized in any way.

Dr. BAHCALL. In the 17 years in which I've been associated with the program, Mr. Walgren, I don't remember a problem being recognized and documented and supported by the scientists as a serious technical problem that wasn't addressed by the project and by NASA. Sometimes they had to be brought kicking and screaming to the correct conclusion, but they always came around.

Mr. NAGLE. The gentleman from Alabama?

Mr. BROWDER. Thank you, Mr. Chairman.

Dr. Stockman, I hate to probe you on something that you've probably covered several times, but there's a point here I want us

to be sure to get. How exactly do we correct the flaw? For example, do we need to actually find the defective hardware? For example, the null lens. Do we need to actually find that to make this correction, or how do we go about correcting it?

Dr. STOCKMAN. Well, I think none of us at this table are actually experts in the very fine detail of optics, but all of us are familiar with these sorts of optics, so I think I'll give you an answer which most of us can nod our heads with.

The desire that Dr. Bahcall stated of the Allen committee finding the exact nature of the problem and therefore, by inference, the prescription for any fix, we all have, because the kinds of measurements we can make on orbit are necessarily limited, particularly in some cases because the measuring systems which are in orbit, which are part of in fact the fine guidance system and were produced by Perkin-Elmer, really did not anticipate this large an error. They were really looking for much subtler things and this size of a problem swamps in many ways the subtle effects they were going to see or they thought they might see.

So it would be best if in fact we can get a very accurate prescription of what the problem is; however, I'm confident that we can measure using what we have up in the spacecraft, imagers and those wave front sensors in the fine guidance sensor, the wave front accurately enough that the corrective optics can be made to bring the images very close to specification, and I would remind the committee about some of the technical capabilities of the spacecraft that really haven't been exercised and can't address the problem at the extent we have it now but could address the problem at a much lower level, at a residual level, should there be a residual image problem at a more refined level.

There still are full motions of the secondary mirror, which can take out certain remaining aberrations, and there still are substantial amounts of aberration that can be taken out in the primary mirror actuators, so one scenario goes like this. If it's not possible to get a perfect prescription but we can rely on the optical tests that we have now and will get in the future to bound what the prescription should be, any residual we see once we launch can be made up now using either the secondary mirror or the primary actuators. So I have high confidence that that is not going to be a show-stopper.

Mr. BROWDER. So your answer is, no, we do not actually have to find the defective hardware.

Dr. STOCKMAN. I don't think it's mandatory. It is certainly desirable.

Mr. BROWDER. Okay.

Dr. Bahcall, you were talking a minute ago in your conversation with my colleague about an error that you picked up and that several of you were free to go look at whatever your special expertise led you to. Do the problems uncovered in the Hubble Program have any implications for future astronomy missions or for other large science missions, such as the Earth Observing System, for example? Is there something now that you want to go look at or think that should be looked at as a result of the Hubble Program?

Dr. BAHCALL. I have to tell you that I am the chair, Mr. Browder, of a National Academy Science committee which works every

decade to set the priorities for space and ground based astronomy missions. The Congress and the agencies have been very wise, I would say, in according a very high priority to our highest priority. I believe astronomy is the only discipline which sets its own priorities.

We have in this activity, which has lasted almost two years, about 20 times as many losers as we will have winners in the final priority list. Certainly, I have to tell you that the lessons that we have learned from the Hubble Space Telescope and from the past 10 years of astronomy missions are affecting our judgments about our priorities.

But according to National Academy rules, I'm not allowed to share those priorities with you, or those views even with you, until they are refereed by the National Academy referees and approved by the President of the National Academy. I look forward to sharing them with you next year.

Mr. WALGREN. You can share your views, couldn't you? I mean, you gratuitously offered that you are chairman of this group, and you have a right to have your own views, I'm sure.

Dr. BAHCALL. I'm afraid at this stage my views are not distinguishable from the committee. I don't think I could. I think that we learned a lot, and I think those have implications for the kinds of missions that the astronomy community will come back to the Congress and to the agencies and recommend as highest priorities.

Mr. BROWDER. Dr. Bahcall, I understand that the Earth Observing System is outside of the scope.

Dr. BAHCALL. Of our committee, that is, sir, and I could offer gratuitous comments on that.

Mr. BROWDER. Could you do that?

Dr. BAHCALL. Well, I'm not very familiar with the system myself, but I must say that some of my best friends are involved in that community, and the impression I have back from them is that they're having many of the same problems that we had and that they're a bit overwhelmed by the size of the system and the magnitude of the data which they would face, and they're not quite sure what they're going to do about it, but they're confident they're going to cope.

Mr. BROWDER. Maybe we need to get some of them here to talk about that.

Thank you, Mr. Chairman.

Mr. NAGLE. Let's adjourn, and I would like to advise you, though, that because you happen to get here on a Friday and you happened to get here on a Friday afternoon that the committee does want to alert you that there are still some areas of inquiry that we have, including some of my own, and we would like to submit additional written questions to you individually and as a panel and then ask you to respond in your own good time, and perhaps that would be even better, because you'd have more opportunity to reflect upon your answers.

I thank you for your testimony today. I'm sure the committee chairman, were he here, would thank you, as would the ranking member. That concludes this hearing.

[Whereupon, at 3:31 p.m., the committee was adjourned, to reconvene at the call of the Chair.]

APPENDIX

ADDITIONAL QUESTIONS FOR THE RECORD
SUBMITTED BY
THE HONORABLE ROBERT ROE
DIRECTED TO DR. LEW ALLEN
Following the July 13, 1990, HST Hearing

Q1. Would you characterize the flaw as one that would be difficult to detect with the tests that were conducted on the telescope or one that would be very obvious?

A1. Perkin-Elmer (currently Hughes Danbury Optical Systems) made a decision that only a reflective null corrector test was precise enough to measure the mirror. In retrospect, if the null corrector was properly made and calibrated then this test was sufficient to detect the flaw and the flaw would be obvious. There were other tests that could have been done at the time, but Perkin-Elmer chose not to do them. We currently know that the reflective null corrector was not functioning properly and therefore was the cause of the incorrect figure of the primary mirror.

Q2. Will the adequacy of the test program and testing philosophy be a subject of your investigation?

A2. Yes

ADDITIONAL QUESTIONS FOR THE RECORD
SUBMITTED BY
THE HONORABLE ROBERT ROE
DIRECTED TO DR. HERVEY P. STOCKMAN
Following the July 13, 1990, HST Hearing

1. The Faint Object Camera (FOC) was provided by the European Space Agency. It's capabilities have been significantly degraded due to the flaw in Hubble's mirror.

   a. Are there any plans to restore its capabilities in the near future?

   b. To what extent have the Europeans been involved in the replanning of the observing program?

   c. European scientists had been allocated 15% of the viewing opportunities on Hubble in exchange for their 15% investment in Hubble. How will that allocation be affected by the loss of a significant fraction of the Faint Object Camera's capabilities?

2. How much do you expect that the initiation of the telescope's science program will be delayed?

3. Since it had been planned to do the most important and highest priority science in the first year of Hubble's time on orbit, when is the earliest that the original plan for the first year's experimental program can be completed?

4. Is the Science Operations Ground System (SOGS) software designed in such a way that it can handle such a drastically revised viewing program as is now being planned or will modifications be required to it?

5. What does the recently discovered Hubble problem do to the estimated operating costs of the telescope? If you don't know yet, when do you expect to know?

Responses to Additional Questions submitted by
The Honorable Robert Roe following the
July 13 1990, HST Hearing

1. Plans for ESA's Faint Object Camera and science programs: To the ST ScI's knowledge, there are no working plans for restoring its capabilities in the near future. Current NASA planning calls for the correction of the mirror's aberrations in new instruments to be installed using Shuttle servicing starting with the WF/PC replacement in 1993. As of several weeks ago, ESA had no plans for building a replacement FOC or follow-on instrument. However, scientists and engineers at NASA, ESA, and the ST ScI continue to consider other solutions to the mirror problems which may restore the original performance to the entire observatory including the FOC. It appears that a single fix to the mirror problem or on-orbit modifications to the existing instruments may still be feasible.

   Astronomers from ESA countries participate in the replanning of the observing program at many levels. ESA has several senior scientists on the NASA-run Science Working Group. Others european astronomers are members of a strategy committee created by the ST ScI to consider various fixes to HST (which is being hosted at the HST European Coordinating Facility on 3-4 September). Senior ESA astronomers will participate in the Space Telescope Advisory Committee meeting on 24 September to consider short-term and long term scientific issues. Finally, all investigators will be requested to readdress their accepted programs prior to a final review by the reconstituted Time Allocation Committee in November.

   In regards to the NASA/ESA MOU guaranteeing ESA astronomers a 15% share of HST's science program, we are not aware of any considerations to increase this share or modify the existing arrangements. The Committee may be interested to know that in the first peer review for Cycle 1, proposals from ESA countries obtained at least that share (a bit more by some measures) without adjustment.

2. The delay in the HST's science program: The HST science program was intended to start approximately three months after launch, intermixed with science instrument checkout. Due in part to the mirror aberrations, the early commissioning program (orbital verification) will end approximately in mid-October, six months after launch.

3. The deferral of scientific programs: While the original science programs continue to be analyzed in the light of encouraging results from early imaging tests, it is clear that the effects of spherical aberration must be corrected before 40-50% can be completed. Most of these programs can utilize the corrected WF/PC replacement. Thus, their completion will be delayed by approximately three years. A small number of the original programs, approximately 10%, will require corrections to other instruments and, thus, will await the installation of second generation instruments or other corrective actions. In this assessment, I have not included secondary effects of the aberration on the pointing control systems. While a definitive understanding of these effects is a few months away, it is likely that certain targets and programs will be affected by degraded pointing performance.

4. The Science Operations Ground System (SOGS): The current SOGS system is capable of executing the revised science program, only requiring a modest number of modifications to reflect the actual performance of the spacecraft, science instruments, and other portions of the ground system. These modifications, as well as the completion of several general capabilities such as those to observe planets and their satellites, are being accomplished under a management and budgetary plan established before launch.

5. Operations costs: First, I must distinguish between the costs for yearly operations (the ground system and science support) and the costs for maintenance and refurbishment (the shuttle servicing program and the development of new scientific instruments). We estimate that the added costs for yearly operations due to the mirror aberrations are relatively minor. Indeed, most of the ground system elements are working to budgets and levels submitted before launch. Added costs in this area will be due to the extended commissioning period and its extensive demands on manpower as well as unanticipated modifications to ground and flight software. Offsetting "savings" may come from the delay in science support of general observers. However, most ground system support manpower is appropriate for normal science and mission operations and will not be significantly affected by the Hubble problem.

   In terms of maintenance and refurbishment, NASA has indicated that the strategy of correcting replacement and second generation instruments will proceed at a somewhat faster pace than the pre-launch M&R plans. An acceleration of instrument development could require additional funding, with early estimates placing the additional costs at tens of millions of dollars over the next three years. Since other strategies continue to be explored, NASA may not commit to a specific timetable and cost until the mirror aberrations are precisely characterized and their secondary effects on the instruments and guidance system are well understood several months from now.

ADDITIONAL QUESTIONS FOR THE RECORD
SUBMITTED BY
THE HONORABLE ROBERT ROE
DIRECTED TO DR. ROBERT BLESS
Following the July 13, 1990, HST Hearing

1. Please provide an update on the status of the Wide Field/Planetary Camera (WF/PC).

2. It has been stated that the capabilities of the WF/PC will be fully restored by the replacement of the existing instrument with a modified one in 1993.

   a. Do you agree?

   b. To the best of your knowledge, when will the remaining Hubble capabilities be restored under the current schedule? Are there any capabilities that cannot be restored?

   c. Can the schedule for replacing the existing instruments be advanced significantly? What are the risks in accelerating the schedule?

3. What do you consider the major unknowns to be in the on-orbit replacement of the Hubble instruments?

4. Given that the replacement Hubble instruments cannot be integrated with the Hubble Telescope in advance, how will they be verified to assure their performance on orbit?

5. Did the Science Working Group propose any tests of the optics after the Challenger-related delay? If so, what was NASA's response? If not, why not?

6. What guidelines were Principal Investigators given regarding on-orbit maintenance and replacement of instruments? Were those guidelines well-defined? Did you have any concerns about the approach taken?

7. Please provide the current status of the day-night jitter problem.

   a. Can you estimate the impact on the scientific program of the current problem?

   b. How much improvement will the proposed fix provide?

8. Given the current Hubble problems, what percentage of the planned observational program do you estimate can be carried out over the assumed 15-year lifetime of the telescope?

The following are my responses to the attached questions for the record submitted to me by the Honorable Robert Roe.

R. C. Bless

1. The current estimate by the WFC team is that about 80 to 85% of their program has been lost as a result of the spherical aberration of the primary mirror. Their observing programs were heavily weighted towards cosmological problems which require the greatest sensitivity and spatial resolution.

2. a) Assuming that the spherical aberration will be accurately specifed and that the WFC II optics properly correct for it, then the originally intended sensitivity and imaging capabilities should be recovered.

b) In mid-August, a meeting was held at the Science Institute to consider all possible solutions to the problem caused by the faulty mirror. Some of these involve the installation of optics which would simultaneously correct the spherical aberration for all of the instruments. The feasibility of such global fixes cannot be assessed at this time, and in what follows I will assume that recovery can be made only at the instrument level.

The project hopes to have the STIS (Space Telescope Imaging Spectrograph) ready for installation in HST in about six years. It is a more efficient and powerful instrument than either of the two spectrographs now on HST and will more than restore the capabilities of those two instruments.

It is not clear whether or not the full FOC capabilities will be restored. The European Space Agency is looking at all possible fixes for the Faint Object Camera with a report expected by the end of the year. As presently planned the STIS will have some capability for high resolution ultraviolet imaging similar to that intended for the FOC. As I understand it, however, some redesign would be necessary for the STIS to accomodate a useful set of ultraviolet filters. Finally, some consideration is being given to installing a higher resolution CCD detector in the WFC II. This, with a UV transmitting and visible blocking filter would enable fairly high resolution UV imaging to be made.

The High Speed Photometer is a rather simple device with the likelihood of a relatively long life. In addition its functions are somewhat more specialized than those of the other instruments. Consequently, it was never intended to provide a second generation HSP nor are there any plans to do so now. Hence its original capabilities will not be recovered.

c) I can comment only in a general way based on information supplied by the respective PI's. Three years to complete and test WFC II is probably reasonable; finishing NICMOS and STIS in six years is somewhat more problematic since they are not nearly as far along as the camera. The PI's feel, however, that both NICMOS and STIS can be ready for launch in six years if the funding is not stretched out. Several months ago, the STIS schedule was delayed about one year to 1997, but if funding were restored it could be delivered in time for a 1996 launch.

3. The major unknown in the on-orbit replacement of a second generation instrument is will it work the very first time it is installed in the focal plane structure? That is, will it fit mechanically, will the thermal environment be as expected, will the electrical connections be correct and made properly, will there be electrical interference between the spacecraft and instrument signals, etc. Also, can the instrument be handled safely and be maintained in a safe thermal environment while it is being installed? None of these is a trivial consideration. For example, despite documentation defining the interface, all of the first generation axial instruments had various degrees of mechanical interference the first time they were installed in the spacecraft because of problems on the focal plane structure side of the interface; another example: the electrical connections of the WFC are made by a blind mating of the two halves of several connectors; that is, the astronaut cannot see the connectors but must rely on guide rails

to position the instrument properly.

4. Several interfaces between the instrument, the spacecraft, and/or the ground must match, for example, mechanical, thermal, power, electronic signals, command and data handling. It should be possible to replicate adequately on the ground these interfaces and Goddard is building a test facility to do that. Even so, there could be problems ranging from simple wiring errors, or not using the "as-built" drawings, to subtle electrical interference effects, since it will not be possible to test the replacement instrument along with the existing instruments to look for electrical "noise".

Probably the WFC II is less likely to have these problems than the other replacement instruments because in its essentials it is a copy of WFC I which was extensively tested in the spacecraft. This is not the case for the other second generation instruments, however. It remains to be seen whether a first-time installation of complex instruments into an orbiting spacecraft is a feasible strategy.

5. The Science Working Group did propose tests of the telescope optics but none of these were motivated by any doubts about the quality of the mirror. The proposed tests which were eventually carried out had to do with measuring the amount of dust on the primary, determining the position of the secondary to make sure an adequate focus range existed, and a crude throughput test to determine that there was not any gross blockage of an instrument aperture by a piece of multi-layer insulation, for example. I do not recall any discussion by the SWG in which doubt was expressed about the quality of the telescope optics. All the information we had was that the optics were superb.

6. The PI's of the first generation instruments were given very few guidelines concerning on-orbit maintenance and replacement of instruments. Essentially all that we were told was that the instruments should be capable of being taken in and out of the focal plane structure on-orbit as well as on the ground. Since most of the hardware to do that was to be provided by NASA and we assumed that the instrument would be dead or effectively so when removed, we had few things to consider.

7.a) If not solved, the day-night jitter problem would decrease the amount of orbital night time available for observing, with a corresponding reduction in the operational efficiency of the observatory. Approximately seven minutes out of a typical night of 35 minutes, or about 20%, would be lost.

b) I don't think it is known just how well the fix will work, but it is needless to speculate since the question should be answered by the end of September.

8. The HST observing program planned at launch consisted of two parts: the projects to be carried out by the instrument teams over the first 3-4 years of the observatory's life (the so-called Guaranteed Time Observer, or GTO); and the first year's program proposed by general observers (GO) and selected by the Science Institute. Between the GTO and GO programs, a total of about two years of telescope time had been committed. Both categories of programs are now being revised to take into account the limitations imposed by the mirror problem. The general observers will continue to compete for observing time at approximately yearly intervals throughout the life of the observatory. In addition, new GTO programs will begin as the second generation instruments become operational.

It is impossible for me to estimate the fraction of the programs planned at launch that will be carried out ultimately. All that can be said is that for the first three years of the observatory's life most of the original WFC program will not be done, though other useful projects will be; after the WFC II is installed, however, the original WFC program could be done. For the first six or seven years about half of the original spectroscopic observations will be obtained; after STIS is installed all of those programs could be carried out. At best, only

about two-thirds of the photometer's program will ever be done. As it now stands, the FOC will be able to make about half of its originally planned programs. Beyond that, the situation for FOC is not clear at the present time, as indicated in 2.b) above.

August 28, 1990

ADDITIONAL QUESTIONS FOR THE RECORD
SUBMITTED BY
THE HONORABLE ROBERT ROE
DIRECTED TO DR. JOHN BAHCALL
Following the July 13, 1990, HST Hearing

Q1. What is the impact of the Hubble flaw on each of the scientific instruments, and what percentage of the planned science can be done on each instrument?

A1. The impact is serious to critical on all the instruments and is still being evaluated.

Q1a. Does the degraded Hubble image quality equally affect all subfields of astronomy? If not, where is the scientific impact greatest?

A1a. The impact is broad, but unequal. One cannot really specify where we are most hurt until we have more experience.

Q2. It is our understanding that to date only the Wide Field/Planetary Camera (WF/PC) and the Faint Object Camera (FOC) have been used to make test observations. If so, on what do you base your estimates of how much science can still be done by the other instruments?

A2. The estimate are based upon ground-based test data of the other instruments and models of the existing HST mirror.

Q2a. When will the remaining three scientific instruments be used for the first time?

A2a. Tests are currently being carried and others are planned in the next few months.

Q3. Since it had been planned to do the most important and highest priority science in the first year of Hubble's time on orbit, when is the earliest that the original plan for the first year's experimental program can be completed?

A3. One year after the installations and testing of the second generation wide field/planetary camera.

ASSOCIATION OF UNIVERSITIES FOR RESEARCH IN ASTRONOMY, INC.
SUITE 701
1625 MASSACHUSETTS AVENUE, N.W.
WASHINGTON, D.C. 20036
202-483-2101

Goetz K. Oertel
President

August 27, 1990

The Honorable Robert A. Roe
Chairman
U.S. House of Representatives
House Science, Space, and
Technology Committee
Suite 2321 Rayburn HOB
Washington, DC 20515

B.6

Dear Mr. Chairman:

It is a pleasure to respond to your letter of August 1, 1990 and two questions regarding the Hubble Space Telescope. I trust that our answers will be helpful.

We appreciate your support for astronomy in space and on the ground and pledge to work with NASA and with NSF to make it pay off as we know it will.

With best regards,

Sincerely yours,

Goetz K. Oertel

GKO/ycw

Answers to Questions of August 1, 1990
from the House Science, Space, and Technology Committee

1. Question: Hubble will operate in a limited mode for the first three years. How will that affect research, training, and people in universities and at the Space Telescope Science Institute? How will their needs be met?

Answer:

a. Hubble's limited mode will reduce its research output. The science that can be done will take longer to do. The balance must await the restoration of Hubble's full capabilities. Research results will have the high quality you can expect from Hubble, though there will be less of them and they will be harder to cull out of the data.

b. Researchers at universities and at the Space Telescope Science Institute will work harder to get results. Fewer of them can get results as soon as expected. These researchers have put their careers and those of their students on the line for Hubble. We need a "safety net" for these people.

The supporting technical staff at the Space Telescope Science Institute, engineers, computer experts, and others, will also work hard to do the best they can for Hubble. They will support researchers in applying innovative techniques to work around the flaw and get the best possible results from Hubble as we wait for the restoration of its full capabilities.

2. Question: In response to a question regarding the placement of telescopes into geostationary orbit, Dr. Fisk indicated that he thought that it was not a good idea since "the Hubble Space Telescope with spherical aberration in geostationary is inaccessible to you, and you could not fix it. The Hubble Space Telescope with spherical aberration in shuttle orbit is fixable...When you do a billion and a half dollar project, it is nice to know that you can make sure it will work." Do you agree? Should the SIRTF Great Observatory be revised to make it serviceable by the Shuttle?

Answer: We believe that SIRTF should not be replanned for low earth orbit but should fly in high earth orbit as planned.

The Space Shuttle was built to have the unique capability for man to intervene and repair and/or recover spacecraft in low earth orbit. We have learned a lot since then. Experience has shown that repair in orbit is a great challenge to our astronauts. We now know what it costs to design spacecraft to be compatible with the Shuttle and to be repairable in orbit, and what it costs to maintain the repair capability on the ground. We also know the cost of launching with the Shuttle.

The costs and risks of Shuttle launch and the ability to repair in orbit should be compared, case by case, with the cost and risk of unmanned launch. The comparison should consider the benefit of freedom from the Shuttle's low earth orbit that imposes unfavorable operational constraints. We believe that NASA's decision to put SIRTF in high earth orbit was sound and support it. Hubble tells us to test systems more fully, not to rely further on repairs in orbit.

Responses to written questions submitted by Chrm. Roe resulting from the July 13, 1990, hearing at which Dr. Fisk testified.

QUESTION 1:

Please provide a description and estimate of the budgetary impacts of the discovery of the spherical aberration on the FY 1990 and 1991 budgets.

ANSWER 1:

Fiscal Year (FY) 1990 costs for Hubble Space Telescope (HST) mission operations and data analysis are estimated to be $3.4 million higher than previously expected. The largest single contributor to this increase is the activity associated with producing the second Wide Field/Planetary Camera (WF/PC II) with modified optics that will fully correct for the aberration in HST's mirror. The key elements in developing the correction will be to (1) precisely characterize the prescription of HST's mirror to the limits of WF/PC II sensitivity, (2) modify the existing WF/PC II mirror simulator so that it produces the exact flaw of the on-orbit mirror (and no other flaws), and (3) rigorous verification and test of both the ground simulator and the instrument to guarantee that only the existing flaw has been duplicated. New FY 1990 activity includes the initial optical analysis and long lead procurements. Funding to support this unanticipated work will be transferred from elsewhere within the budget line for mission operations and data analysis.

Any additional FY 1990 costs due to a greater-than expected effort with on-orbit checkout have been accommodated by deferring non-time-critical procurements within the HST program. The efforts of the Hubble Space Telescope Optical System Board of Investigation, chaired by Dr. Allen, and the team supporting it have been funded at $350,000.

There will be an impact to the FY 1991 OSSA budget due to HST's spherical aberration, however, any additional funding requirements will be accommodated from elsewhere within OSSA's FY 1991 budget. Annual operating costs will remain unchanged even in its current condition; HST is heavily oversubscribed and will be conducting scientific investigations 365 days a year. The importance of the replacement instruments has increased because the spherical aberration can be corrected by these instruments, thus enabling us to realize the full potential of HST. While the cost of the optical corrections are expected to be minor, particularly for the instruments following WF/PC II which have not yet completed the design phase, the optimal phasing of the instrument development may be reexamined given the current situation. However, any such reassessment will be made in the context of the overall scientific priorities.

QUESTION 2:

The WF/PC is only one of five instruments affected by the Hubble flaw:

a. How do you intend to restore the capabilities of the other instruments?

b. When will the capabilities be restored under the current (POP-91) schedule?

c. If the approach is to wait until an advanced instrument is available rather than building a replacement instrument, what modifications will be required to the advanced instruments to counteract the aberration?

d. Can the schedule for replacing the existing instruments be advanced significantly? What are the risks in accelerating the schedule?

e. What do you consider the major unknowns to be in the on-orbit replacement of the Hubble instruments?

f. Can the effects of the aberration be completely corrected for on the other instruments, or will they always be degraded to some extent?

ANSWER 2a:

The High Speed Photometer (HSP), Faint Object Camera (FOC), and the Goddard High Resolution Spectrograph (GHRS) will be able to accomplish over 50 percent of their original goals with HST in its current condition.

The scientific goals that cannot be met now will be accomplished by the planned Space Telescope Imaging Spectrograph (STIS), a second generation instrument whose 1996-1997 target launch date is under assessment due to the spherical aberration problem. The STIS can also achieve many of the original goals of the FOC.

b. Under the current schedule, WF/PC II will be installed on orbit in June 1993. The next two replacement instruments, STIS and the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS), are planned to be ready for installation during servicing missions in late 1996/1997.

c. The only change needed in WF/PC II, STIS, and NICMOS is to alter the prescription on some of their internal mirrors or lenses. Once the prescription error of HST's primary mirror is determined, this is a relatively simple alteration.

d. We are studying the acceleration of all three instruments (WF/PC II, STIS, and NICMOS). We will not, however, accelerate the schedules at the risk of performing all required tests, including an end-to-end test that verifies that the new instrument can accept and correct for a spherically aberrated beam of light which duplicates the current HST optical system.

e. The residual unknown, after we have completed the planned environmental testing for each instrument, will be whether the instruments will function as expected following on-orbit installation into an Observatory system that they have never

actually seen before, except via an electrically- and mechanically-equivalent, high fidelity systems simulator on the ground.

f. The effects of spherical aberration can be completely eliminated through the replacement instruments.

QUESTION 3:

Given that the replacement Hubble instruments cannot be integrated with the Hubble Telescope in advance, how will they be verified to assure their performance on orbit?

ANSWER 3:

All electronic interfaces will be verified through the use of the HST simulator. An end-to-end test that verifies that the new instrument can accept and correct for a spherically aberrated beam of light which duplicates the current HST optical system will be conducted.

QUESTION 4:

Please provide the current status of the day-night jitter problem.

ANSWER 4:

A flight system software change is scheduled to be uplinked to HST in mid-October which should significantly reduce or eliminate the jitter effect caused by the current day-night transitions. This software modification is currently undergoing ground testing and verification procedures.

a. Can you estimate the impact on the scientific program of the current problem?

b. How much improvement will the proposed fix provide?

ANSWER 4a:

The current impact is solely a scheduling problem; the most critical observations are being scheduled around the day-night transitions to avoid potential data loss.

b. The planned software modification, once uplinked and tested, should bring HST within or very near its original stability specifications. This will make scheduling of orbital operations simpler, with little or no impact on scientific return due to the residual jitter.

QUESTION 5:

There has been some discussion of using digital image enhancement techniques on the ground to restore some of the lost science:

a. How effective would these techniques be?

b. Can the processing techniques be used on all of the observations of the five science instruments, or are there some instruments that could not benefit? What percentage of the science can be recovered or improved with these techniques?

c. Are there any penalties to the efficiency of the observing program associated with using such processing techniques?

d. How much extra would it cost to do the proposed digital image processing?

ANSWER 5a:

Four days after announcement of the HST optical problem, an Image Processing Working Group (IPWG), consisting of top experts in this area was formed to assist experts already working within the Principal Investigator Teams and the Space Telescope Science Institute (STScI). On July 6, the IPWG issued the following statement:

"Given our current understanding of the Hubble Space Telescope performance, we expect that post-detection processing may achieve a factor of 2 to 3 improvement in resolution for high signal-to-noise ratio observations. To achieve this improvement, an accurate characterization of the telescope aberrations is imperative. Further improvement in resolution is theoretically possible through modes of operation not envisioned at time of launch. Examples of these modes may include increased integration time and multiple focal settings."

In fact, the nature of the image profile, with its bright core, makes image recovery procedures especially effective in cases in which one is trying to extract information on bright sources against a diffuse or dark background. This situation arises fairly often in astronomy.

As is generally the case with image restoration techniques, their value tends to be a strong function of the kind of image one is studying and the kind of measurement one wishes to extract. We will adjust our science strategy in the years prior to the 1993 servicing mission to capitalize on those studies which most benefit from image processing.

b. Only the HSP and Fine Guidance/Astrometry System will not benefit from image recovery techniques. The science return from WF/PC, FOC, GHRS and the Faint Object Spectrograph (FOS) will be enhanced by image processing. The degree to which that return is enhanced depends on the type of object under study, the desired measurement and the source brightness. As we gain experience with image processing, the magnitude of its contribution will become better understood.

While an important technique, it is unlikely that image restoration will ever be more than one of a number of tools useful in optimizing the scientific return of HST.

c. Except for the brightest objects, longer exposure times may be required. For some extremely high priority sources, the suggestion has been made that multiple images, with the telescope in different configurations, could be combined as part of the image recovery process. This would involve a substantial penalty in observing time but does seem a likely prospect.

d. There may be additional costs associated with image recovery data processing, with some requirement for increased expertise and, especially, additional computing and display facilities. Some image processing would probably have been done in any case, and some of the required talent and computational power may already be in place. There is, as yet, no estimate of additional cost, in part because experimentation with image processing procedures is still in progress.

QUESTION 6:

The latches for fastening the instruments on the telescope were a source of repeated problems during the Hubble development program. How confident are we that they will not be a problem during the on-orbit replacement of the instruments?

ANSWER 6:

The latches must precisely position new science instruments in the focal plane of the HST and insure adequate thermal transfer characteristics across the instrument-spacecraft structure interface. During their development, problems were encountered with positional repeatability due to prelaunch loading, thermal fluxes and galling of the latches. These problems were solved during the development program, as demonstrated by the many prelaunch tests to which the latches were subjected prior to their final acceptance for flight and by actual flight performance to date.

QUESTION 7:

Can telescope servicing be handled from the present Phase I Space Station Freedom?

a. Would servicing be possible from the original Phase II station?

b. What is the impact of the deletion of servicing "hooks and scars" from the Phase I Station?

c. How does termination of the Orbital Maneuvering Vehicle development program affect NASA's ability to service the telescope, either from the Shuttle or Station?

ANSWER 7:

No. Servicing of spacecraft such as HST would require an Orbital Maneuvering Vehicle (OMV) to bring them to the Space Station. NASA plans to service the HST using the Space Shuttle, so no provisions are being made in the Space Station design to

accommodate HST servicing.

a. Yes. The original Phase II design included the development of an OMV and a servicing bay that could have been used for HST servicing.

b. Deletion of the studies related to the Station servicing facility and associated scars will have no impact on HST operations or servicing. NASA is still studying future servicing requirements for the Space Station as they relate to the President's Space Exploration Initiative.

c. Termination of the Orbital Maneuvering Vehicle (OMV) program has no effect on NASA's ability to service HST from the Shuttle. The lack of an OMV prohibits HST servicing from Space Station Freedom.

QUESTION 8:

What major refurbishments will be needed on Hubble during its lifetime, and what is the plan for accomplishing such refurbishments?

a. How soon do you expect that the Hubble mirrors will have to be recoated? On what do you base your estimate?

ANSWER 8::

Refurbishment of HST during its 15-year operational life will be accomplished through on-orbit replacement of Observatory equipment. All such Orbital Replacement Unit (ORU) changeouts and advanced science instrument upgrades will be performed using the Space Shuttle.

The most important refurbishment for HST, and the key element in the entire observatory concept, is the ability to replace the original instruments (based on late-1970's technology) with replacement instruments which use state-of-the-art technology. Investment in new instruments will account for approximately three-quarters of the new hardware development planned for HST's operational lifetime.

Other refurbishment is intended to maintain the current level of performance over HST's 15-year operational life. The batteries and the solar arrays have a predictable degradation of capability over time, and thus it is anticipated that a full replacement of batteries and solar arrays will be required approximately every 5 years on-orbit. Subsystems with moving parts are considered most likely to suffer a failure, and so regular replacement of tape recorders, rate gyros, and reaction wheels is anticipated. Additional fine guidance sensors are likely to be required to replace the three currently on-orbit and the one spare. Finally, there are over forty other types of orbital replacement units which are on hand in case they are required.

The actual sequence of servicing missions will be determined by the availability of replacement instruments, hardware

degradation, unanticipated failures, and the potential need for a reboost to prevent orbital decay.

a. We do not anticipate that any re-coating will be required.

QUESTION 9:

What is the expected cost for servicing the telescope on a per-mission basis?

ANSWER 9:

There are two types of costs associated with a servicing mission. The first is roughly analogous to the Office of Space Science and Applications (OSSA) flight systems mission management and integration associated with Shuttle payloads. There are also additional costs for simulation and training associated with astronaut Extravehicular Activity (EVA), some of which is shared with the Office of Space Flight, which are necessary to conduct the servicing mission. The mission management costs of a specific HST servicing mission are estimated at $20-$30 million, depending on the complexity of the cargo to be installed.

The other cost of a particular servicing mission is the development and maintenance of the new instruments and orbital replacement units which are installed during that mission. Investments in spacecraft infrastructure are an integral part of the life-cycle strategy to maintaining a functional observatory over HST's planned 15-year operational life, and to take advantage of advances in instrument technology over the same period. About 70 percent of the costs of the HST servicing program go towards these investments in infrastructure.

The planned cargo for the first servicing mission planned for 1993 has not been baselined, but it is likely that less than $100 million of investments will be installed. The marginal cost of a dedicated Shuttle flight is additive.

QUESTION 10:

What level of Shuttle capability was assumed in the decision to accept higher risks in the telescope design due to the expected availability of Shuttle servicing?

a. What contingency plans exist to reflect the lower numbers of Shuttle flights planned in post-Challenger flight manifests?

b. How do these contingency plans account for episodes like the present case where the Shuttles are grounded due to problems?

ANSWER 10:

The earliest HST planning called for a Shuttle servicing mission every two years with a ground return mission every four years. In the late 1970's, this timeframe stretched to servicing every 2.5 years and ground return every five years. This latter scenario was assumed in establishing the initial HST design

requirements. The program was modified in 1982 for on-orbit servicing only. During the post-Challenger period, significant changes and upgrades were made to the Observatory to make HST as robust as possible. The current scenario involves on-orbit servicing missions (only) on essentially 3-year centers, with one or two missions over the expected life of the telescope somewhat more frequently to enable adequate changeout of ORUs and ORIs, as required.

a. None. The current flight rate can accommodate all known HST requirements.

b. Such scheduling uncertainties are implicitly acknowledged in the HST program's agreement with the Office of Space Flight to conduct a repair mission within 12 months of a failure which results in reducing HST to dependence on a single string of equipment in any critical subsystem. This approach has been accepted as a reasonable contingency trade. Events such as the one referred to are completely unpredictable and therefore specific prior planning cannot account for them. It was uncertainty such as this, coupled with the desire to make HST less sensitive to degraded operations, that led to the activities cited above to make the overall Observatory-ground operations system more robust.

QUESTION 11:

It has been stated that it would have cost more than $100 million to build and operate a facility to test the Hubble optics on the ground. Do you agree?

ANSWER 11:

Numerous end-to-end electrical and electronic systems tests were conducted on HST during the preparation for launch, but a "to-specification" full aperture end-to-end test of the HST optical system was not conducted. The $100 million figure that has been discussed is an estimate of the cost required to develop the capability to conduct such an end-to-end "to-specification" full-scale optical system test and then to conduct that test. Because of the size and precision of HST's primary mirror, this full aperture test would have required a very unique ground facility, which included a large diameter (larger than HST's primary mirror) optical flat, ground to better precision than HST's primary mirror. Building such a flat would, in turn, have required additional facilities not known to exist at that time or even today. Finally, there would be significant schedule impacts and substantial risk of degrading the ultraviolet performance of the telescope by contamination during testing. One hundred million dollars appears to be a conservative estimate for such a test given the stringent requirements.

Even given the existence of such a facility, another major problem would have been mitigating of the effects of the Earth's gravity on the shape of the telescope structure and on the primary mirror. Given the design requirements for the flight system, we do not know how such a capability could have been

constructed for such a test.

QUESTION 12:

Did NASA prescribe any type of testing procedure in its solicitation? What were they specifically? -- Did the mirror contractor propose any beyond what were required by NASA, and were they ultimately performed? What role, if any, did NASA play in the testing? What is the process for certifying that the tests were successful?

ANSWER 12:

NASA specified the optical system performance requirements and gave broad guidelines for the system test and verification programs. The details of the test program were expected to be developed by the winning contractor and provided to NASA for approval. To assure that all requirements are verified, a matrix was prepared by the contractor and approved by NASA which related the detailed system specifications (as called out in the Contract End Item Specification) to the specific test which demonstrates compliance to some portion of those specifications. This process is consistent with procurements of this type which are typically employed by U.S. Government agencies.

The contractor originally proposed a 0.5 meter optical throughput test at the integrated system level for the purpose of providing an optical stimuli to the Fine Guidance Sensors (FGS) and the Optical Control Subsystem (OCS). This test was later removed by the contractor, primarily to save the spacecraft weight and complexity associated with the addition of the telescope equipment needed for the test. The objectives of this test were instead met by more cost effective techniques utilizing equipment located outside the Observatory.

Test plans and procedures were reviewed by representatives of NASA or the Defense Contract Administrative Services (DCAS). Where deemed appropriate, mandatory inspection points were identified in the procedures and execution was witnessed by a government representative. Criteria for successful completion of the tests were established before each test was conducted and results were compared with these criteria through in-progress technical reviews.

QUESTION 13:

Several experts have questioned the wisdom of not performing independent tests to verify the results of the contractors' tests? How do you respond to this criticism?

ANSWER 13:

The strategy for the HST program was always to precisely measure each of the mirrors independently and then use straightforward analyses to predict the performance of the assembled Optical Telescope Assembly (OTA) system. Details of this approach were widely circulated throughout the optics community by publication

of technical papers in appropriate industry journals and had the endorsement of that community at the time. Full aperture testing of the total OTA was never deemed meritorious by the contractor, by the optics community, or by NASA.

The HST test concept was based on the premise that the primary and secondary mirrors could be individually fabricated and verified. The only remaining verification requirement was proper spacing between the two mirrors. This spacing was verified by a much simpler and less costly test than a full aperture end-to-end test. However, the lack of some form of independent verification testing for the primary mirror, whether by Perkin-Elmer or another organization, was a critical deficiency in the OTA optical system development program.

QUESTION 14:

What visibility did NASA have into the contractors' testing activities?

ANSWER 14:

The Marshall Space Flight Center (MSFC) had a three-person resident staff at the Hughes Danbury Optical Systems (HDOS, formerly Perkin-Elmer) facility at the time that the mirrors were being polished. Those personnel and others from MSFC who were at the HDOS facility on a temporary duty basis had full access to the documentation, test hardware, flight hardware and all technical discussions pertaining to the program while resident there. In addition, DCAS personnel were resident at HDOS during the optics polishing program to monitor operations. Three scientists, Dr. Fastie, Dr. O'Dell and Dr. Schroeder, were charged by NASA to oversee the optics development program.

QUESTION 15:

What effect did early cost overruns and management problems have on the amount of testing?

ANSWER 15:

The optical test program that HDOS proposed and that NASA/MSFC agreed to, except for the above mentioned 0.5 meter optical throughput test, was the one that was performed. No optical testing was deleted because of cost or management problems.

QUESTION 16:

Was funding ever transferred from test and verification to cover cost overruns in other parts of the program?

ANSWER 16:

The scope of test and verification activities increased substantially during HST's development in order to accommodate the unanticipated technical complexity of the job. For example, a thermal-vacuum test of the entire observatory was added to the

program after development was initiated.

QUESTION 17:

Hughes-Danbury (formerly Perkin-Elmer) is currently eligible to receive over three million dollars in award fees based on an evaluation of the on-orbit performance of the Hubble Optical Telescope Assembly:

a. How will the discovery of the spherical aberration affect the amount of the award fee?

b. When will NASA make that decision?

ANSWER 17a:

The HDOS on-orbit award fee is composed of several award fee pools associated with different elements of performance, only one of which is mirror performance. Spherical aberration is a critical flaw in mirror performance, and so if it is determined that the contractor is responsible for the aberration in the mirror, then the fee associated with mirror performance will not be awarded.

b. The decision on the HDOS on-orbit award fee is tentatively scheduled for November 15, 1990, pending final confirmation of the nature and cause of the optical problem.

QUESTION 18:

The NASA Inspector General (IG) notes that NASA failed to include contract provisions for retroactive adjustments in award fees and that NASA renegotiated the Hughes-Danbury contract performance review:

a. What incentives exist for contractors to perform efficiently if NASA has no flexibility to adjust the award fee based on total performance?

ANSWER 18a:

In a typical cost-plus-award-fee contract, the contractor is evaluated periodically and earns award fee based on performance during that period.

If there is an increase in the cost required to complete the work called for by the contract which is not due to a new task being placed on the contractor by the government, then the contractor earns no base fee on that work. Overruns such as this may also reflect adversely in the performance fee for that period.

QUESTION 19:

What is NASA doing to incorporate the IG's recommendations concerning management practices in its current programs such as the Space Station and the Earth Observing System?

ANSWER 19:

The general thrust of the recommendations in the IG report are directed toward the use of cost-plus-award-fee contracts and specific management practices related to the HST program.

NASA is committed to careful management of the contracts for the Earth Observing System (EOS) program, comprised of EOS platforms, instruments, and the EOS Data and Information System (EOSDIS). Management for the EOS project will be conducted by the Goddard Space Flight Center (GSFC), with the General Electric (GE) Company of New Jersey as the prime contractor for development of the first EOS platform. GSFC has extensive experience in project contract management, including the current successful effort with GE to develop the Upper Atmosphere Research Satellite, upon which the EOS platform approach is based. The award fee plan for the UARS and EOS spacecraft are very similar, and is an effective management tool in the event of cost overruns or delays. GSFC uses the Performance Management System to track progress by their contractors. This system affords GSFC management the opportunity to continuously monitor contractor performance and to identify problems early so that corrective action can be taken in a timely manner.

GE will provide two platforms for the EOS program, EOS-A and EOS-B, and will also be responsible for the integration and testing of the scientific instruments. Investigations for the Scientific Instruments were selected under the EOS Announcement of Opportunity. The day-to-day management of the instruments will be the responsibility of the instrument Principal Investigators, whose institutions will have the responsibility to complete the hardware requirements. Facility instrument contractors will be selected under multiple Requests for Proposals to be issued by the respective NASA Centers. It is NASA's intent that the GSFC EOS Project Office will retain overall management responsibility for the design, development, fabrication, assembly, test and delivery of the Principal Investigator and Facility instruments.

The EOSDIS Phase B Definition contracts were completed in April 1990, with Phase C/D (system development) contract award expected in early 1992. Contract management for the EOSDIS will also be similar to that described above.

As for the specific recommendations of the IG, we are currently reviewing them to see if any of them pertain to the specific management of the EOS program, and will take action on all relevant suggestions as appropriate.

QUESTION 20:

Do any current programs (e.g., AXAF, GRO) have an award fee arrangement similar to that used with Hubble?

ANSWER 20:

All NASA cost-plus-award-fee contracts for research and

development are similar in that they are in accordance with the cogent federal legislation and administrative rules.

The contract for HST with HDOS had a fixed fee of 3 percent as well as award fee based on periodic performance, completion of interim milestones (including Optical Telescope Assembly delivery), and on-orbit performance.

The contract proposed by TRW to develop the Advanced X-ray Astrophysics Facility (AXAF) has been negotiated with no fixed fee and with a potential award fee pool in excess of 10 percent. Therefore, all fee paid to TRW on this contract must be awarded on the basis of either periodic or on-orbit performance, which should increase the incentive effect upon the contractor. Unlike the HST contract with HDOS, the AXAF contract with TRW enables the government to reclaim all provisionally awarded on-orbit performance fee if on-orbit performance warrants such actions.

The contract with TRW to develop the Gamma Ray Observatory (GRO) has a fixed fee of about 1 percent and a potential award fee pool in excess of 10 percent. There is also a potential fee pool associated with on-orbit performance, and another potential fee pool which is associated with the final allowable cost of the contract.

QUESTION 21:

How has the recognition of the Hubble anomaly changed NASA's approach to building and testing the other Great Observatories such as AXAF and other complex space platforms such as the Space Station and the Earth Observing System (EOS)?

ANSWER 21:

The mission concepts for all of NASA's programs, including the Earth Observing System (EOS), the Advanced X-ray Astrophysics Facility (AXAF), and Space Station Freedom, are based on years of careful analysis by NASA engineers and scientists, the scientific community, and various advisory panels. We are confident that our current program designs constitute a careful and reasonable approach to achieving mission success. NASA carefully assesses the risks which could threaten mission success associated with each program and has designed a multiple element strategy to minimize these risks.

EOS elements which reflect this strategy include: 1) use of a series of replacement platforms; 2) availability of replacement launches when evidence of instrument/platform degradation is detected but before platform failure; 3) reliance on redundant spacecraft and instrument subsystems; 4) use of multiple instruments with a successful flight heritage; and 5) a global system of multiple large platforms (U.S., European Space Agency, and Japan) and smaller Earth observing satellites.

The actual design and payload concept for the EOS platforms and instruments is intended to minimize risk to the program. The 5-year design life will be accomplished by eliminating single point

failures, by utilizing redundant systems, and by rigorous parts testing and qualification. Investigation of historical failure rates indicates that Earth science satellites and instruments have consistently performed up to (or beyond) their projected lifetimes, without any significant degradation or abnormal failure rate. Science instruments planned for flight on the EOS platforms will benefit greatly from past experience with similar instruments and recent testing of prototypes aboard aircraft and satellites. Testing of the instruments individually and in an end-to-end manner as part of the integrated platform is a baselined program requirement and is intended to identify any areas of concern well before launch.

Because many of the lessons learned for HST's problems prior to 1983 have already been incorporated into NASA's approach to the AXAF program, HST's current optical system anomaly has not significantly influenced NASA's testing approach on AXAF. Furthermore, there is a long-standing requirement to conduct an end-to-end test of AXAF's optical system prior to launch. Conducting such an end-to-end test is much more straightforward with an x-ray telescope than with a visible light or ultraviolet telescope; x-ray telescopes are not subject to the same stringent contamination or accuracy requirements. A test facility is currently under construction at the Marshall Space Flight Center which will be used to conduct AXAF's end-to-end test. Nevertheless, any subsequent lessons learned that emerge from the Allen Board or elsewhere will be incorporated, as appropriate.

QUESTION 22:

It appears that the only hope for restoring significant scientific capabilities to Hubble will be servicing and repair flights by the Shuttle sometime in the next few years. The large EOS platforms, on the other hand, will be in polar orbit and cannot be serviced or repaired by the Shuttle. What approach should NASA take to assure EOS data continuity, given that the loss of a platform or one of its instruments could lead to loss of vital environmental data for up to five years?

ANSWER 22:

The EOS Program adopted the platform replacement approach as a result of several NASA studies on risk issues. In order to meet the measurement goals of EOS science, the EOS program consists of two series (EOS-A and EOS-B) of polar orbiting platforms which will be replaced every five years to achieve the 15 year mission lifetime goal. The first platform of the EOS-A series will launch in FY 1998, with the first platform of the EOS-B series ready for launch two and a half years later. In the event of a launch vehicle or early on-orbit platform failure, the development schedule for processing subsequent platform copies is such that the platform/instrument suite can be replaced within 3 years. This is possible because the EOS Program has designed the two subsequent platform copies (and instrument copies) to be identical to the original platform. The approach described best assures achieving scientific objectives of long term, simultaneous data measurements.

Other aspects of the approach to minimizing disruption of EOS platform operations were addressed in the answer to the previous question.

QUESTION 23:

Is independent verification and validation of testing needed for the large, complex platforms being developed by NASA, and if so, how can this best be accomplished?

ANSWER 23:

The Goddard Space Flight Center (GSFC) will be responsible for the development and integration of the polar platforms for the Earth Observing System. GSFC has a strong history of successful project management, a record accomplished through careful testing and oversight of missions as they develop. Though history is not always a perfect guide, we are convinced that GSFC has both the resources and the expertise needed to insure a successful EOS program.

Each of the EOS platforms is designed for a five year lifetime, a design feature which depends mostly on the lifetimes of the instruments. This 5-year design life will be accomplished by eliminating single point failures, by utilizing redundant systems, and by rigorous parts testing and qualification. The design review and testing process at GSFC will insure that each stage of the platform development and integration process will be carefully "peer" reviewed by GSFC scientists and engineers from other parts of the Center, and from other NASA Centers when appropriate. While the instruments themselves are being provided by the individual instrument Principal Investigators or instrument teams, the EOS project will carefully monitor their performance and progress in a similar manner.

Careful oversight of the contractors and verification and validation of their performance through extensive testing will ensure successful spacecraft development and a successful mission.

QUESTION 24:

In response to a question regarding the placement of telescopes into geostationary orbit, you indicated that it was not a good idea since "the Hubble Space Telescope with spherical aberration in geostationary is inaccessible to you, and you could not fix it. The Hubble Space Telescope with spherical aberration in shuttle orbit is fixable...When you do a billion and a half dollar project, it is nice to know that you can make sure it will work." Does NASA intend to make the SIRTF "Great Observatory" serviceable by the Shuttle?

ANSWER 24:

No. The Space Infrared Telescope Facility (SIRTF) will be located in a very high circular orbit at an altitude of

approximately 100,000 km. This choice of orbit was influenced by the mission requirement for cryogenic cooling, i.e. the entire optical system and scientific instruments are housed in a large dewar filled with liquid helium. Locating SIRTF in High Earth Orbit (HEO) reduces the operational complexity associated with a cryogenically-cooled spacecraft. HEO also extends the spacecraft's operational lifetime substantially by distancing it from the effects of Earth's thermal radiation.

The only parts of the SIRTF mission that could be designed to be serviceable would be: (1) some spacecraft elements (warm electronics, solar arrays, etc.), or (2) refilling the cryogen tanks. For (1), the Jet Propulsion Laboratory (JPL), which is responsible for SIRTF development, has an excellent record for manufacturing reliable spacecraft for deep space (e.g. unserviceable) missions in their planetary exploration program. For (2), SIRTF's operational lifetime in HEO of 5 years is adequate without refill to meet mission requirements. In addition, the process of refilling these tanks is an unproven technology; reliance on refilling the cryogen tanks would result in increased mission risk.

QUESTION 25:

The flaw in the Hubble Space Telescope's optical system was discovered relatively early in the planned orbital verification ["checkout"] period. What other major verification tests remain to be done, and when will they be carried out?

ANSWER 25:

Although a significant amount of work remains before the 8-month orbital verification/science verification period is completed, all of HST's systems and subsystems have been operating since launch, and considerable time has also been dedicated to the instruments. At this time, the exact nature of the optical system's spherical aberration problem is in the process of being characterized, as well as the detailed characteristics of each of the instruments. Therefore, no additional anomalies of significance are anticipated, though one can never be sure for leading-edge programs such as HST.